A STUDY OF THE TRANSMISSION OF *SCHISTOSOMA HAEMATOBIUM* IN VOLTA LAKE, GHANA

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ABSTRACT

A field study on the ecology and epidemiology of *S. haematobium* was carried out in 8 different parts of the Volta Lake from November 1978 to June 1980. Snail sampling for *B. rohlfsi* was conducted monthly in 39 lakeside villages and data on human prevalence rates and egg counts were obtained in 30 of the villages. A detailed, integrated study of *S. haematobium* was conducted at the large lakeside village of Agbenoxoe.

The snail sampling technique was an efficient version of the man-time method. For screening urine samples for *S. haematobium* eggs, the "Nuclepore" filtration method was used - its first large-scale, field application. At Agbenoxoe, a new method of recording water contact data was initiated.

From snail sampling, it was learned that *S. haematobium* transmission was distinctly seasonal, and intensity varied according to the type and amount of vegetation in water contact points (WCPs), the shape of the WCPs, and their geographical location. *S. haematobium* infection rates in *B. rohlfsi* around the lake were among the highest in the world. The snail had a high intrinsic rate of natural increase, but could not maintain an equilibrium population in the unstable habitat of the lake. An original mathematical model was developed to describe the dynamics of *S. haematobium* transmission to *B. rohlfsi*.

S. haematobium prevalence rates and egg counts were exceptionally high in 2 lake sections - the Afram and Obosum branches - mainly because of past and present growth of *Ceratophyllum* which led to high transmission during most months of the year. However transmission became interrupted when *Ceratophyllum* density became too great and decayed in WCPs. Levels of infection were lower in the other lake sections surveyed, mainly because of less *Ceratophyllum* growth which confined high transmission to December to March each year. Analysis of all the human data revealed that the 5 - 19 year-old age span was responsible for 93% of the potential contamination of *S. haematobium* eggs in the Volta Lake.

At Agbenoxoe, snail sampling, prevalence, egg count, incidence, and water contact data fit together to paint a uniform picture of very focal and seasonal transmission.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL CONSIDERATIONS

Schistosomiasis in Africa is an ancient infection, as evidenced by a description of haematuria in a papyrus about 3000 B.C. and the finding of calcified eggs in Egyptian mummies dating back to 1250 B.C. (Ruffer, 1910).

Until the 20th century, transmission on the continent was confined to limited foci: in the Nile basin, mainly in seasonal irrigation canals; in the forest and savannah regions, mainly in streams, small rivers, natural lakes, and ponds.

The rapid increase of population in the 20th century and the opening up of the continent with permanent roads radically altered the ecological equilibrium between man and the parasite. Dams had to be built in large numbers to conserve water and feed expanding irrigation schemes. By the roads came more settlements, reservoirs, culverts, and ponds. The infection moved rapidly into these new ecological niches.

The most serious development which accelerated the spread of schistosomiasis in arid parts of Africa was the change from basin to perennial irrigation. This was especially widespread in Egypt and Sudan. There, the lifeblood of agricultural production was the annual flooding of the Nile. Formerly, dikes and embankments held enough of the flood water for one annual crop to develop in low lying fields. But this type of agriculture could not meet the demand for more food and cash crops.

The shift to perennial irrigation originated in the Nile basin late last century and spread slowly up the Nile. Large reservoirs were built to store flood water and prevent widespread inundation of the fields. The stored water was released slowly and steadily to the fields through vast networks of earth-lined canals, allowing a succession of crops throughout the year.

Snail populations quickly infested the irrigation networks: *Bulinus truncatus* in the canals and *Biomphalaria alexandrina* in drains in the Nile delta. One of the largest epidemics of *S. haematobium* and *S. mansoni* in the world had begun. The completion of the first Aswan dam in 1902 and its heightening in 1933 led to the rapid spread of perennial irrigation and *S. haematobium* infection to upper Egypt.

Three years after the introduction of perennial irrigation to four areas of Quena and Aswan provinces, the prevalence rate of S. haematobium in all age groups increased from 2 - 11% to 44 - 75% (Khalil, 1949).

The most comprehensive survey of schistosomiasis in Egypt was conducted by J.A. Scott (1937). In 1934, he estimated that almost 60% of 10 million people living in districts with perennial irrigation were infected with S. haematobium, while 3 million people (almost exclusively in the northern delta) were infected with S. mansoni. In the districts where basin irrigation was still practised, only 5% and 0.1% of the inhabitants were infected with these two species respectively.

The Sennar Dam across the Blue Nile in Sudan was completed in 1924. By 1938, the impoundment it formed fed major and minor canals that extended over 4,000 km through the Gezira irrigation scheme. Before the project, schistosomiasis was not detected in the area (Humphreys, 1932). But between 1940 - 1945, about 20% of the adults and 45% of the children living in the Gezira had acquired S. haematobium (Stephenson, 1947). S. mansoni developed in the later extensions of the Gezira and Managil schemes, rising from approximately 5% among children in 1947 to about 80% in 1973 (M. Amin, personal communication). The construction of the Rosaires Dam in 1966 eliminated dry periods in the new canals, and seems responsible for the upsurge in transmission. The intensity of S. mansoni among residents in the greater Gezira has now reached one of the highest levels in the world (World Health, 1980).

There are numerous reports of schistosmiasis becoming endemic in previously non-endemic areas following water development projects. Yet, in the past 25 years, there has been an acceleration in the construction of small, medium, and large dams in Africa. It is impossible to estimate accurately the number of small dams being built each year on the continent. At present, it could be well over 10,000. In the Nyanza provice of Kenya alone, 50,000 small impoundments were created between 1957 and 1960 (Hunter, Rey, and Scott, unpublished WHO report, 1979).

Table 1 lists those African countries which had one or more large dam (over 15 m in height) in 1977. Over half of the number listed were built after 1960.

Table 1. Number of dams over 15 m high in 31 African countries, 1977. (Source: World Register of Dams, ICLD, Paris, 1979.)

South Africa[1]	317	Benin	4	Ghana	2
Zimbabwe	69	Cameroun	4	Guinea	2
Morocco	23	Madagascar	4	Lesotho	2
Algeria	21	Sudan	4	Sierra Leone	2
Tunisia	20	Zambia	4	Zaire	2
Angola	9	Botswana	3	Liberia	1
Ethiopia	8	Egypt	3	Mali	1
Mozambique	6	Ivory Coast	3	Tanzania	1
Nigeria	5	Malawi	3	Togo	1
Kenya	5	Congo	2	Uganda	1
				Upper Volta	1

The 160 m high Coborra Bassa Dam in Mozambique and the 25 m high Kpong Dam in Ghana were completed in 1980. Additional major dams in endemic areas are being built or planned on: the Gorgal River, Mauritania, the Senegal River at Diama, Senegal; the Biafing (Senegal River) tributary, at Manantali, Mali; the Sassandra River at Buyo, Ivory Coast; the Niger River at Kandadji, Niger; the Black Volta River at Bui, Ghana; the Zaire River at Inga, Zaire; the Ghania River, near Nairobi; and the Great Ruaha River at Mtera, Tanzania.

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[1] In South Africa, schistosomiasis is not yet a major problem in the largest man-made lakes, most of which are at fairly high altitudes, where water temperature is too low to support vector snail populations. But the potential for schistosome transmission is increasing downstream from some of the big dams because impoundment and subsequent discharge increases water temperature to a point where vector snails can tolerate it (Pitchford and Visser, 1975).

The economic need for building large and small dams cannot be disputed. But too often, the effect of impoundments on human health has not been considered. This is especially the case with small dams, increasingly being built by local contractors, outside of national or international supervision.

Largely as a result of water development projects, the number of people infected with schistosomiasis in Africa is estimated to be be as high as 91 million (W.H. Wright, 1972), and at least 144 million are said to be exposed to the infection (Iarotsky and Davis, 1981).

Serious clinical syndromes have long been recognized in human cases of S. japonicum or S. mansoni. Until 1966, S. haematobium was generally considered of minor public health importance in sub-saharan Africa (WHO, 1977). But that year, Forsyth and Bradley (1966) described how S. haematobium caused vesicular and ureto-renal lesions, including bladder calcification, hydroureter, hydronephrosis, and non-functioning kidneys among more than 20% of children and 10% of adults in a Tanzanian community. Other documentation of manifest disease caused by S. haematobium in Africa have included reports by Gilles et al. (1965a, 1965b), Forsyth and MacDonald (1965), Forsyth (1969), Gelfand (1971), Rugemalila (1978), and a special study in the WHO schistosomiasis project in Ghana (final unpublished project report, UNDP/WHO, Geneva, 1979).

In postmortem studies and among hospitalized patients, S. haematobium infections have been associated with functional renal disease, in some cases leading to death (Lehman et al., 1970; Smith et al., 1974). But following chemotherapy, chronic S. haematobium lesions have been shown to be reversible (Lucas et al., 1969). Although Abdel-Salem and Abdel-Fattah (1977) found that pathology of S. haematobium correlated positively with egg counts, a recent analysis of Tanzanian field data by Rugemalila (PhD thesis, University of London, 1981) has shown that serious sequelae from S. haematobium infections are often unrelated to egg levels in positive urine samples.

Some attempts have been made to quantify economic loss or human disability from schistosome infections (Pesigan et al., 1958: Farooq, Samaan, and Nielsen, 1966; Foster, 1967; Fenwick and Figenchou, 1972; Gateff et al., 1971; W.H. Wright, 1972; Weisbrod et al., 1973). All were inconclusive for several reasons, one of which is that schistosome infections, in general, do not result in easily-measurable parameters of debility (Forsyth, 1969; Walker, Walker, and Richardson, 1970).

Despite world-wide attention given to health problems caused by the largest man-made lakes in Africa and elsewhere (notably, Lowe-McConnell,1966; Obeng, 1969; Ackermann, White, and Worthington, 1973; Stanley and Alpers, 1975), there has been no major study of schistosome transmission and infection at or near any of these lakes outside of Ghana. (Some details of the largest African man-made lakes and schistosome transmission in them are summarized in Table 2).

Small-scale prevalence and snail surveys were conducted at Lake Kariba (Hira, 1969, 1970) and at Lake Kainji (Dazo and Biles, unpublished WHO reports, 1971, 1972; Teesdale, unpublished WHO report, 1971). Virtually no work has been done at Lake Koussou (Scott and Chu, unpublished WHO report, 1974; Deschiens and Cornu, 1976). Only recently, have systematic surveys begun at Lake Nasser (unpublished UNDP/WHO report, 1980).

By far the most information on schistosomiasis in a large man-made lake has come from studies at the world's largest man-made lake, the Volta Lake, in Ghana. A review of this research is therefore important, and constitutes a section of this thesis.

Country Dam Yr. finished	Lake name Area, km^2	Approximate no. people resettled	Est. no. of people living at lake	Schistosome species	Vector snail species	Schistosome transmission at lake
Zambia & Zimbabwe Kariba 1958	Kariba 5180	56,000	Unknown	*S. haematobium* *S. mansoni*	*B. (P.) africanus* *B. pfeifferi*	Focal, limited Sporadic
Ghana Akosombo 1964	Volta 8730	70,000	200,000	*S. haematobium*	*B. rohlfsi*	Focal, but in all sections of lake
Nigeria Kainji 1968	Kainji 1243	44,000	44,000	*S. haematobium* *S. mansoni*	*B. globosus* *B. pfeifferi*	Focal, limited Very light
Egypt Aswan High 1969	Nasser 5250	120,000	8,000	*S. haematobium*	*B. truncatus*	Focal, limited
Ivory Coast Koussou 1972	Koussou 1500	80,000	75,000	*S. haematobium* *S. mansoni*	*B. globosus* *B. pfeifferi*	Unknown Unknown

Table 2. Summary of largest man-made lakes in Africa and schistosome transmission in them.

Plate 1. Composite view of Volta Lake from satellite photographs.
Scale = 1 : 2,000,000

1.2 GENESIS AND PURPOSE OF PRESENT RESEARCH

Most of the research conducted at the Volta Lake occurred in the WHO schistosomiasis and control project that ran in Ghana from late 1971 to December 1978. The author was a staff member in the project, from 1973 to 1978.

The idea of the present research began when the WHO project was about to close. Because of financial constraints, field work in the project had been confined mainly to one small section of the lake, covering about 60 km of shoreline. Doubts remained whether conclusions reached on the status of *S. haematobium* in the study area would be valid for the lake as a whole.

Therefore, the purpose of the present study was to collect information on the ecology and epidemiology of *S. haematobium* in different lake sections, to make comparisons with results from the WHO project, and, more important, to discover aspects of the biology of *B. rohlfsi*, and ecology of *S. haematobium* transmission that were hitherto unknown for the snail and parasite in a man-made lake habitat.

The major part of the study involved monthly snail sampling in 39 lakeside villages, in 8 different lake sections. A second aspect involved data collection on *S. haematobium* prevalence rates and egg output in 30 of the villages. The final aspect included an in-depth study of *S. haematobium* transmission and infection at one large lakeside village - Agbenoxoe. All of the field work took place from November 1978 to June 1980.

Since much of the present research is the logical extension of earlier work at the Volta Lake, it is necessary to review in some detail these earlier studies, many of which were never formally published, or appeared in obscure journals. This is dealt with in chapters 2 - 4.

Chapter 2 reviews findings on *S. haematobium* in Ghana, before and after the formation of the lake, to 1973.

Chapter 3 briefly reviews the WHO schistosomiasis project from 1971 to 1978, its success in reducing *S. haematobium* in the study area, and some problems encountered in evaluating the efficacy of the intervention measures.

Chapter 4 describes the basic ecology of water contact points in the Volta Lake, the development of snail sampling techniques applicable in the lake, and important precontrol findings from snail sampling in the WHO study area.

All aspects of the present research are presented in chapters 5 - 10.

Chapter 5 describes the organization and coverage of the snail sampling surveys, and the sensitivity of the chosen snail sampling method.

Chapter 6 presents detailed analysis of the snail sampling data, emphasizing the seasonality and focality of *S. haematobium* transmission as determined by ecological factors. It also includes a study of the growth, fecundity, and survivorship of *B. rohlfsi*, and an original mathematical model to describe the dynamics of *S. haematobium* transmission to Volta-Lake *B. rohlfsi*.

Chapter 7 describes the location and ecological features of all 39 sampled villages, and presents summary results of snail sampling on a village-by-village basis.

Chapter 8 gives results from epidemiological sampling in 30 of the villages, mainly to describe *S. haematobium* prevalence rates and levels of egg output, but also to determine age-specific levels of contamination potential, incidence rates by catalytic model application, and variation in levels of infection in different parts of the lake. A section is devoted to describing the "Nuclepore" filtration method for *S. haematobium* eggs, how it was adapted for large-scale use in Ghana, and how it compared with the filtration method used in the WHO project.

Chapter 9 presents results of the in-depth research at Agbenoxoe, where different studies attempted to "tie-together" facts gathered on the seasonality and focality of transmission, and age and sex differences in infection.

Chapter 10 summarizes the main findings of the present research, gives conclusions, and offers recommendations for future academic and public health work on *S. haematobium* in Ghana.

1.3 SOME POINTS AND WORDS TO CLARIFY

Until the WHO schistosomiasis project in Ghana, the intermediate snail host for *S. haematobium* in the Volta Lake was referred to as *Bulinus truncatus rohlfsi* (Clessin, 1886). But following malacological observation of the snail in Ghana by Dr. K.Y. Chu (personal communication) and taxomic studies at the British Museum of Natural History, the snail was called *Bulinus rohlfsi* in published articles stemming from the WHO project, and in the definitive book, *Freshwater Snails of Africa and Their Medical Importance* by Dr. D.S. Brown (1980). Hence, it is referred to as *Bulinus rohlfsi* in this report.

The term, "water contact point" (WCP), is used herein to describe each small area in the lake - always at the end of a village footpath or road leading into the water - where people have regular water contact. In previous articles by the author and other members of the WHO project, each of these "points" was called a "water contact site" (WCS). Since the latter term is sometimes used by others to describe a wide area, perhaps covering an entire village shoreline, it was felt that "water contact point" would give a more precise meaning, since most WCPs in the Volta Lake encompass an area of less than 40 m in width (along shore, parallel to shore) and 20 m from the shoreline to deeper water.

Another term used frequently is, "snail infection rate". Unless otherwise stated, this refers to the fraction or percentage of *B. rohlfsi* found to be infected with patent (mature) *S. haematobium* cercariae.

Two Ghanaian words used commonly are, "Ewe", and, "Agbenoxoe". Ewe, referring to the tribe, is pronounced, ĕ-vāy, and Agbenoxoe, the village, is pronounced, ăg-bĕn-ŏch'-wāy.

CHAPTER 2

HISTORY OF THE OUTBREAK OF SCHISTOSOMIASIS AT THE VOLTA LAKE

2.1 ASPECTS OF THE GEOGRAPHY OF GHANA

Ghana lies in a central position along the Gulf of Guinea in West Africa, the southernmost tip being 4° 44' north of the equator. The coastline is 550 km long and the mean north-south distance is 675 km. At the last census in 1970, the population was about 10 million; it was probably over 12 million by 1980. Greatest densities occur along the coast, in the southern forest zone, and in the far northeast and northwest. The least populated area of Ghana extends along the western and northwestern side of the Volta drainage basin.

This basin occupies two thirds of Ghana; in its lowest parts lies the Volta Lake, itself occupying almost 4% of Ghana. It receives every major river running through the country except the Densu, Pra, Akobra, and Tano rivers to the south and southwest (Map 1). The south basin narrows into a v-shape as it meets the Voltaian escarpment on the southwest, the Akwapim range to the south, and the Togo range on the southeast. These are small mountain ranges, rising no more than 300 to 800 m above sea level.

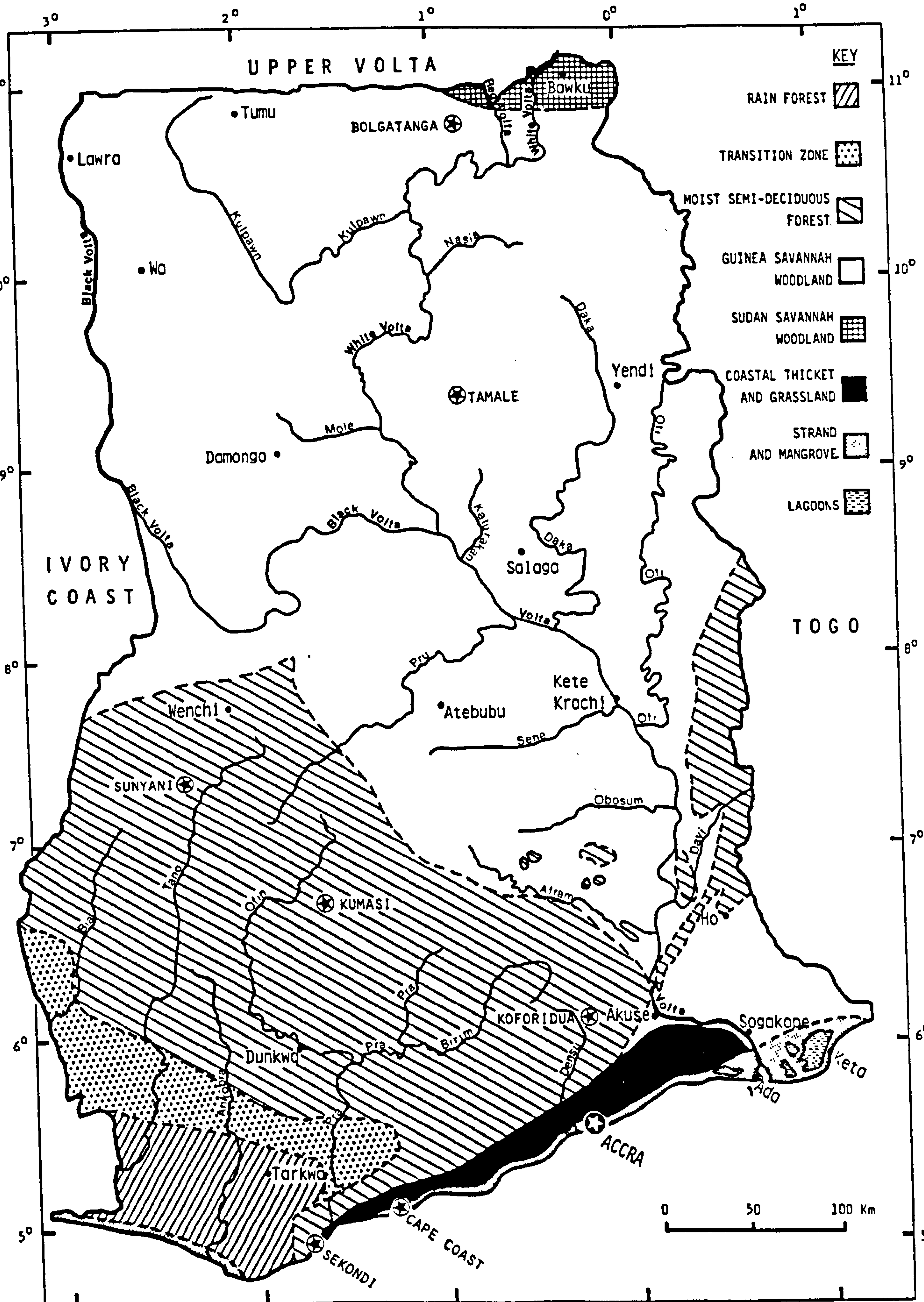
With so much flat land, temperature variation is slight throughout the country. The average temperature is 26°C on the coast and 28.8°C in the far north.

Apart from the coastal grasslands, rainfall averages between 1150 - 1900 mm (45 - 75") in the southern half of Ghana and between 1000 - 1400 mm (40 - 55") in the northern half. Most rain falls from April to June, and September to October in the south, and from June to September in the north. The calmest and dryest period is from November to January when all of Ghana is covered by dusty, "harmattan", air originating from the Sahara Desert.

Daytime relative humidity is generally over 70% along the coast, 65% in the forest zone, and 60% in the northern savannah.

2.2 CREATION OF THE LAKE

The Volta Lake started to fill in May 1964 upon completion of the dam at the Akosombo gorge. The scheme was part of the Volta River Project, the principal goal of which was to stimulate diversification of the Ghanaian economy by providing cheap hydroelectric energy for aluminium production,



Map 1

Ghana before the formation of the Volta Lake showing major vegetation zones, rivers, and towns.

other industries, export, and domestic electrification, thereby lessening Ghana's dependence on exports of primary commodities, especially cocoa.

From an ititial height of 13.7 m above sea level, the water rose to 82 m in November 1967 and reached a maximum height of 84.2 m in November 1969. At the latter level, the newly formed lake had a shoreline of over 5,000 km, a mean depth of 19 m, and an annual fluctuation of between 2.5 and 6 m.

The flooded river valleys and stream tributaries give the lake a dendritic shape, and it stretches over 400 km from Akosombo to Yapei in the north. Except for small sections of the Afram, Pawmpawm, and Dayi River branches in the moist forest zone, the entire lake lies within the Guinea woodland savannah zone.

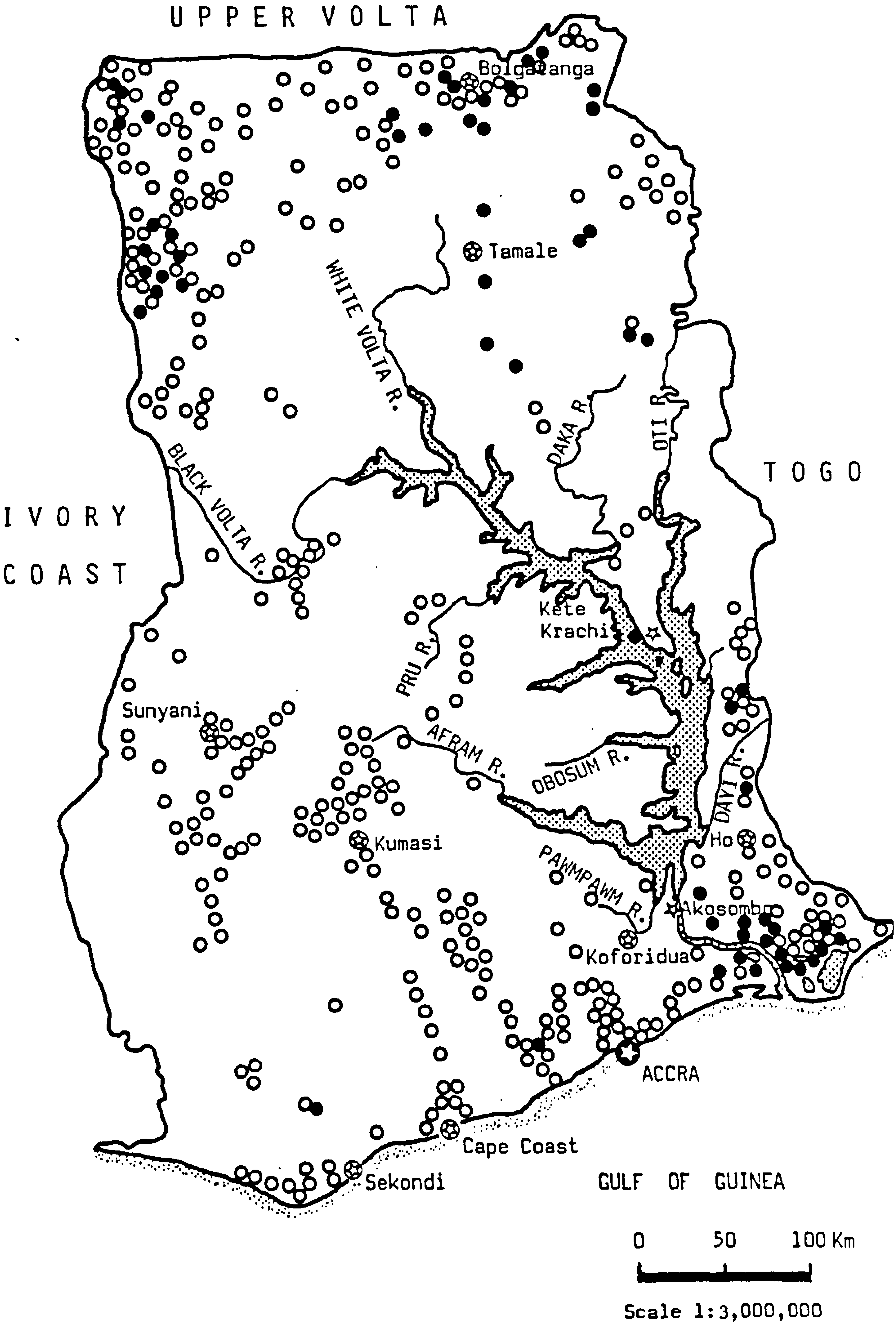
2.3 PRE-LAKE DISTRIBUTION OF THE SNAIL HOSTS OF *S. HAEMATOBIUM*

Map 2 shows the known distribution of *B. globosus* (plain circles) and *B. rohlfsi* (black circles) in Ghana prior to the lake, but with the lake illustrated as a reference. The map was constructed from maps and reports by McCullough (1955, 1957a, 1962, 1965) and Odei (1964).

Only one focus of *B. rohlfsi* (in a reservoir near Kete Krachie) and few *B. globosus* foci were found by McCullough (1965) in the area now occupied by the lake. However, the small reservoir at Kete Krachie was the only one of many small lakes along the middle course of the Volta River that was surveyed (Paperna, 1969a). McCullough (ibid) attributed the paucity of the snail hosts in the Volta basin to the effect of the Voltaian rocks which underlies almost the entire area. Before the lake, the porous nature of this geological base led to a long shortage of surface water during the dry season, and this was inimical to survival of the two snail species.

The greatest concentration of *B. rohlfsi* was in the Volta delta where McCullough (1962) and Paperna (1968a) found the snail in fresh water lagoons and swamps. In the other areas of Ghana, the snail was found in perennial pools of some northern rivers, in large ponds, and reservoirs.

B. globosus was widespread throughout Ghana outside of the Voltaian



Map 2

Known pre-lake distribution of B.globosus (○) and B.rohlfsi (●) in Ghana showing the present area of the Volta Lake.

rock formation. It was mainly found in perennial streams, river pools, and small reservoirs in the forest zone, pools, rain ditches, and small reservoirs in the coastal plains, and small reservoirs, and drying river pools in the more arid north (McCullough, 1955; Odei, 1964).

Biomphalaria pfeifferi was also widely distributed in the forest and savannah zones outside of the Voltaian rock formation. Unlike B. rohlfsi and B. globosus, it was not found in any area now occupied by the Volta Lake (McCullough, 1965).

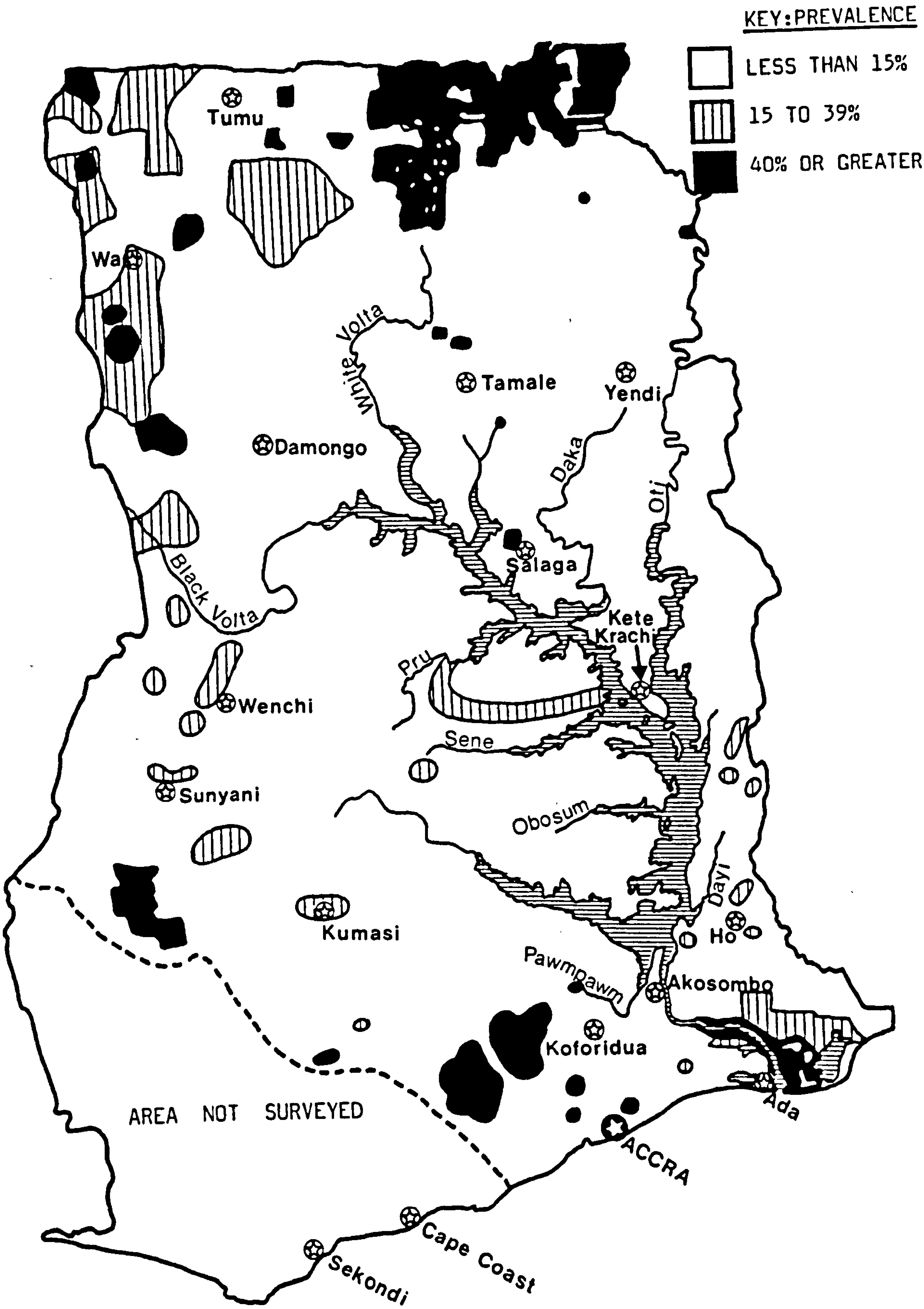
Brown (1980) cites an identification of Biomphalaria camerounensis by McCullough in Kumasi in 1965. However, the indigenicity of this species in Ghana has never been confirmed by subsequent findings.

Apart from a few endemic foci, S. mansoni was an uncommon infection in Ghana until recently (K.Y. Chu, personal communication).

2.4 PRE-LAKE DISTRIBUTION OF S. HAEMATOBIUM IN GHANA

Map 3 pieces together areas in the country before the lake formed where the prevalence rate of S. haematobium in boys 5 to 15 years old was known the range from 0 to 15% (clear areas), 15 to 40% (hatched), and generally over 40% (black). The information was assembled from various published maps, based mainly on results of extensive surveys by the Ghana Medical Field Unit (Waddy, 1956). The most accurate part of Map 3 is in the Volta Region (southeast) where careful surveys were conducted by Onori, McCullough, and Rossi (1963). The information from the northwest came from Odei (1964). For the rest of the country, information was less precise, coming from McCullough (1965), Paperna (1969b), and from a recent, unpublished survey (by the author) around Breman-Asikuma in the Central Region (assuming stable prevalence rates during the past decade). It should be noted that no focus of S. haematobium prevalence over 15% was ever reported in all the surveys for any district within the present boundary of the Volta Lake.

The high prevalence rates along the lower reaches of the Volta River and around the southeastern lagoons was primarily due to transmission of the "rohlfsi" strain of S. haematobium by B. rohlfsi (Paperna, 1968c). In the other areas of Ghana, infection was almost exclusively by the "globosus" strain, transmitted by B. globosus. McCullough (1957b, 1959)



Map 3

Pre-lake distribution of S. haematobium infection in Ghana among boys 5 to 15 years old, and present area of the Volta Lake.

found that the globosus strain either did not develop or developed poorly in _B. rohlfsi_; similarly, the rohlfsi strain showed a low compatibility in _B. globosus_. Paperna (1968c) found that the globosus strain of northern Ghana was compatible with local _B. globosus_ but significantly incompatible with _B. globosus_ from southern Ghana and vice versa. In contrast, _B. rohlfsi_ snails from both north and south were equally susceptible to infection by the rohlfsi strain from different regions.

2.5 EARLY MIGRATION OF PEOPLE TO THE LAKE

The area flooded by the lake was formerly inhabited by approximately 80,000 people living in about 700 villages (Kalitsi, 1973). In 1964, this represented over 1% of Ghana's population. About 67,000 of these displaced people were resettled by the Volta River Authority (VRA) in 52 newly built resettlement communities scattered around the lake (FAO/UNDP, 1971). By 1968, almost 54,000 of the people had moved out of the VRA villages, due mainly to a shortage of farming land near the settlements, lack of water supply, and over-crowding in the one-to three-room resettlement units. Some moved to nearby fishing villages but most had "gone elsewhere" (ibid).

With newcomers moving into the vacant resettlement houses, the estimated population in the 52 VRA villages in 1968 was 43,500 (ibid). In all but a few of these villages, the water supply either never worked or broke down soon after the people arrived. In those resettlement villages within 5 km from the lake, people were dependent upon the lake for their water supply during most of the year.

The lake created a new ecological niche for both riverine fish (northern sectors) and lacustrine species (southern sectors), and from 1965 to 1966 there was a rapid expansion of populations of commercially important species of _Tilapia_, _Alestes_, _Synodontus_, _Labeo_, _Hemichromis_, _Lates_, and _Hydrocynus_ (Petr, 1969).

As early as 1965, fishermen at the lake were catching fish in record numbers. The VRA had predicted a maximum fish yield of 20,000 metric tons per year during the first decade of the lake. But in 1969 alone, over 61,000 metric tons were harvested (Bazios, unpublished data, 1969). News of the large fish harvest spread quickly to towns and villages below the dam along the Volta River and Volta delta, the home area of Ewe and Ada fisherfolk. Ga-Adangbe, Efutu, and Fanti fishermen from the east-central and central coast were also attracted to the lake. The government imposed no restrictions of settlement around the lake, so a rapid migration began to all parts of the lakeshore. Before 1964, the number of fishermen in the Volta basin above the dam was estimated to be 1,200 (Butcher, 1973). By 1970, the number fishing full-time around the lake was not less than 12,500 (ibid), and perhaps as high as 20,000 (Evans and Vanderpuye, 1973). With a sample ratio of 1 fisherman to 5 accompanying family members (FAO/UNDP, 1971), the total population of fisherfolk in 1970 was thus 60,000 to 100,000 in over 950 hamlets and villages around the lake.

People living in hinterland villages within daily walking distance of the lake began farming the fertile soil of the drawdown area. Precise population figures are unavailable; however, a demographic survey by Chu, Klumpp, and Kofi (unpublished data) for the Pawmpawm and southeast Afram branches of the lake revealed that the number of people living in villages 1 to 5 km from the lake (who depended on the lake for farming, part-time fishing, or regular water contact during most of the year) was 1.1 times the number of people enumerated in all known lakeshore villages in the same vicinity. Assuming that this ratio is reasonable for the whole lake, the total number of people in 1970 who had daily or frequent contact with the lake might have been as high as 250,000 - 2.5% of Ghana's population at that time.

2.6 FORMATION OF WEEDS AND THE EARLY SPREAD OF _B. ROHLFSI_ IN THE LAKE

In comparison with the extensive weed problem at Lake Kariba (Boughey, 1963), less than 1% of the Volta Lake was ever covered by aquatic vegetation (Hall et al., 1969). The only serious weed growths developed in the riverine ends of the Afram and Pawmpawm branches between 1966 and 1970 when extensive "sudds" of _Scirpus cubensis_, _Pistia statiotes_, and _Scirpus-Pistia_ mixtures covered most of the water and made boat movement impossible (Lawson, 1967; Hall and Okali, 1974).

As the Volta Lake started to fill, small clusters of _Pistia_ and _Pistia_ mixtures invaded from river pools and small lakes, including the small lake near Kete Krachie where McCullough (1962) had earlier found

B. rohlfsi. These were spread rapidly around the lake by wind and wave action. In September 1966, wide mats of Pistia were reported by Paperna (1969a) along the shores of Ampem (Afram branch), Yeji (mouth of Pru branch), and the new site of Kete Krachie. The plants were "heavily populated" with B. rohlfsi, and finding over 50 snails on some Pistia specimens was common at Ampem. By 1967, Paperna (ibid) reported the breakup of Pistia in all 3 villages along with a concomitant reduction of B. rohlfsi. The weed die-off was part of a general breakup of the limited sudd condition observed by Pierce (1971)[1] in his surveys around the lake between 1976 and 1971.

During 1967, Paperna (ibid) noted that B. rohlfsi was becoming most abundant on the submerged, floating weed, Ceratophyllum demersum, especially on the south shore of the Afram branch where wide belts of the weed were forming. Initially, fragments of Ceratophyllum were widely dispersed in floating mats of Pistia-Scirpus associations (Lawson, 1967).

From 1967 to 1972, Ceratophyllum grew in heavy density only in the Afram branch and parts of the Pawmpawm and Dayi branches, all of which are in the forest zone. Apart from scattered patches in some sheltered inlets and coves, the weed did not become established in any lake section within the Guinea woodland savannah zone (Pierce, ibid; Odei, 1972)[2].

Although Paperna initially found large numbers of B. rohlfsi on Pistia and Ceratophyllum, the percentage infected with patent S. haematobium cercariae was low. Of 1328 B. rohlfsi collected by Paperna (1970), in "town areas" between 1966 and 1968, only 23 (1.7%) shed furcocercariae.

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1 Pierce, P. Aquatic weed development, impact, and control at Volta Lake, 1967-71. Unpublished mimeographed report carried out for USAID-Volta Lake Technical Assistance Project (641-11-190-028), June 1971.

2 Recent changes in the distribution and density of Ceratophyllum in the lake are discussed in chapter 7.

Plate 2. Ewe boy with large catch of Nile perch (Lates niloticus) at Volta Lake, 1973.

Plate 3. Section of a Volta-Lake fishing village.

Plate 4. Belt of very dense Ceratophyllum demersum in Afram branch of lake, 1977.

Plate 5. Finding Ceratophyllum for the first time in Pru branch of lake, 1978.

After the lake filled in 1968, the water level fluctuated more gradually. Zones of emergent weeds developed on the western side of the lake, dominated by Polygonum senagalense and Vossia cuspidata. Alternanthera sessilis, other sedges, and slender grasses were common in the drawdown area but could not tolerate prolongued flooding. The steeper eastern shore contained less marginal vegetation (Pierce, ibid). In many areas, the emergent plants along the drawdown area created a wide barrier between shore and deep water during peak water level and early drawdown. In this period, channel-like openings had to be cut through the plant zone for canoe passage to the open water. These human water contact points were thus well defined and small in area. This factor enhanced infection of B. rohlfsi by S. haematobium miracidia, and snail infection rates increased. Between 1970 and 1972, the total percentage of naturally infected B. rohlfsi with patent S. haematobium cercariae was 7.6% in the Afram branch (Jones, 1973).

2.7 STATUS OF BULINUS GLOBOSUS AND BIOMPHALARIA PFEIFFERI IN THE LAKE

Paperna (unpublished data) found B. globosus in the lake in 1968, but at only one site - near a stream at Ntonaboma in the Obosum branch. This finding was later substantiated by Odei (cited in Jones, ibid) who, between 1970 and 1972, found the snail in 3 other foci near streams in the same lake branch. Despite searches around the lake by Odei (1972), the snail was not found in any other location.

B. pfeifferi was never observed in the lake. Its closest known focus to the lake was in the Dayi River, about 2 km from the lake proper (Jones, ibid).

2.8 THE EPIDEMIC OF URINARY SCHISTOSOMIASIS AROUND THE LAKE

The influx of thousands of Ewe fisherfolk from the Volta delta (where the rohlfsi strain predominated) started an epidemic of urinary schistosomiasis in almost all parts of the newly formed lake. Paperna (1970) collected evidence to suggest that the infection was due to local transmission.

Paperna's work in Ghana, part of an Israeli technical aid programme, ended in 1968. There was no further research on schistosomiasis at the lake until 1970. Then, the health component of the Volta Lake Research Project (a joint FAO, UNDP, and Ghana Government operation), headed by a WHO epidemiologist, C.R. Jones, began carrying out surveys on the prevalence rate of S. haematobium in children living in lakeside villages.

Between 1970 and 1973, Jones's team managed to complete qualitative urine examinations from almost 14,000 children, aged mostly between 5 and 14, in 137 different villages. Six of the villages had been surveyed previously by Paperna (1970) for S. haematobium infection in children aged about 5 to 19. Sketchy data on the prevalence rate of S. haematobium in areas around the same 6 villages before the lake formed were also available. By piecing together all of the above information, it has been possible to document the rise in the prevalence rate of S. haematobium in these villages from a period before the lake formed to 1973 (Table 3).

Table 3. S. haematobium prevalence rates among children approximately 5-19 years old.

Branch of lake	Village	Pre-lake records 1959-1961 %	Post-lake surveys 1967[c] %	1968[c] %	1970-73[d] %
Afram	Ampen	< 5 [a]	37	44	83.1
Afram	Adawso	< 5 [a]	-	19	89.4
Afram	Asuboni	< 5 [a]	-	8	89.0
Afram	Amate	< 5 [a]	2	33	56.1
Oti-Volta	K. Krachie	3 [b]	36	45	42.7
Pru-Volta	Yeji	2 [b]	36	28	43.4

a - Presumed from outpatient records at Nkyene-Kyene Health Centre; b,c - from Paperna (1970); d - from Jones (1973); last survey in each village.

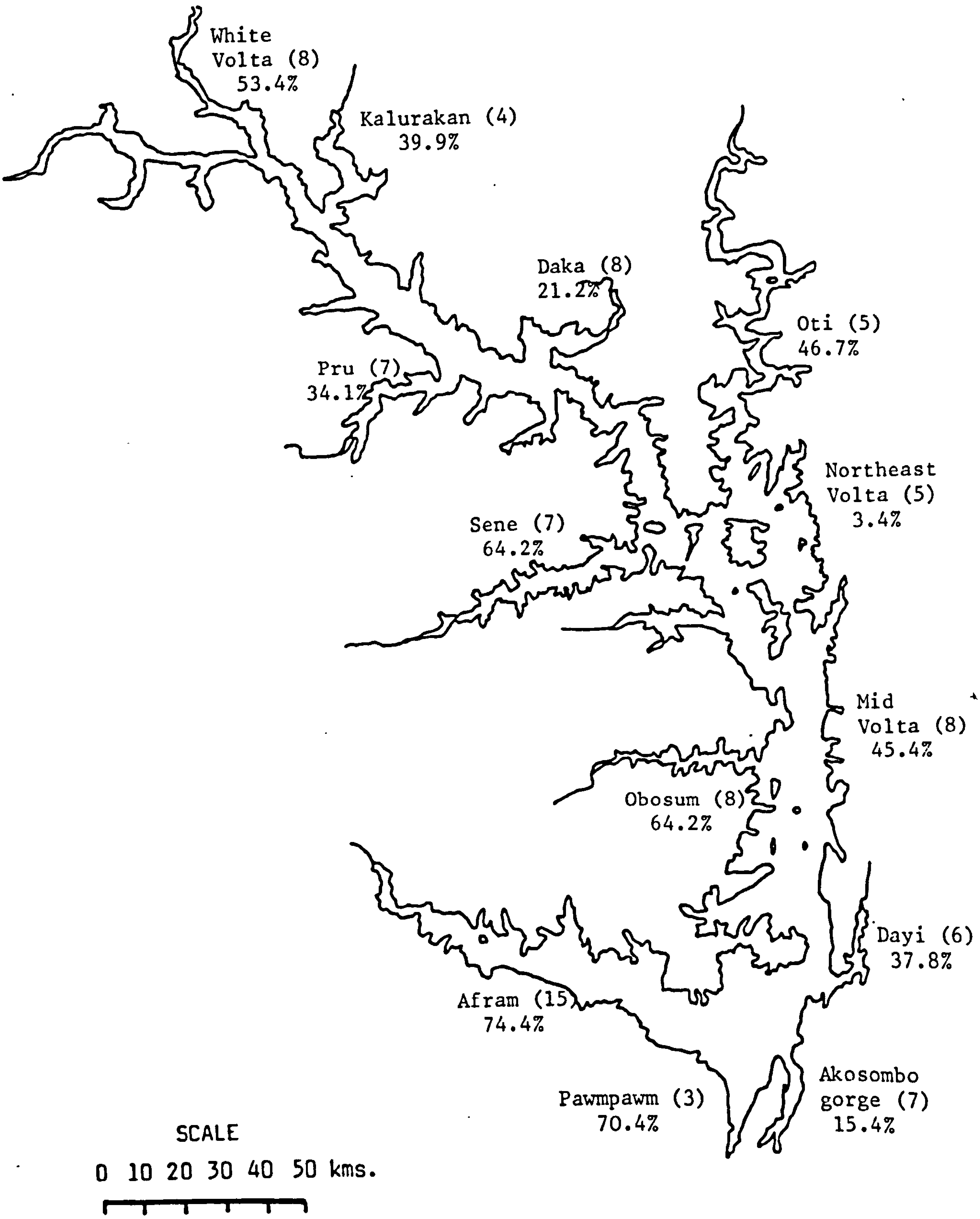
Jones (1973) presented detailed information on the number of children per sampled village that were infected with *S. haematobium*. From the data, it was possible to map the overall, unstandardized prevalence rates in the children by grouping the villages by lake section (Map 4). The rates were calculated from results of the last prevalence survey in each village that was within approximately 3 km of the lake. The finding of high prevalence rates in most lake sections confirmed the truth of earlier predictions (E.G. Berry, unpublished report to N.I.H., 1954; MacDonald, 1955; McCullough, 1965) that damming the Volta River would greatly increase *S. haematobium* infection in the Volta basin around the new lake.

The highest recorded prevalence rates between 1970 and 1973 were in the Afram branch where *Ceratophyllum* was most widespread. The surveys also revealed that prevalence rates were generally lowest in villages on the eastern shore compared to villages on the western shore. Berry (unpublished report to WHO, 1971) suggested that fewer snails could colonize the eastern shore because of its greater exposure to the prevailing westerly winds, and steeper banks.

Prevalence rates were generally lowest in the northeastern, more riverine sectors of the lake. In one of the northern branches, the Daka branch, all indigenous children examined by the VLRP (Jones, ibid) were negative for *S. haematobium* infection. The overall prevalence rate of 21.2% in the branch was the result of infections in non-indigenous children. Although some *B. rohlfsi* were collected by the VLRP in this branch between 1970 and 1973, not a single speciman contained patent *S. haematobium* cercariae.

In all other sections of the lake studied, the VLRP (ibid) established that there was no significant difference in prevalence rates between Ewes and non-Ewes, and that active, local transmission of *S. haematobium* was occurring.

In the same report, the VLRP presented evidence to show that prevalence rates of *S. haematobium* were increasing in towns and villages along the Volta River and Volta delta below the dam. Some of the evidence suggested that much of the increase (between 1970 and 1972) was due to children making frequent trips to the Volta Lake.



Map 4

Overall prevalence rates among children approximately 5 to 14 years old and number of villages surveyed (in parentheses) at different sections of the Volta Lake, 1970 - 1973 (from Jones, 1973).

CHAPTER 3

A REVIEW OF THE MAIN ACTIVITIES AND RESULTS OF THE UNDP/WHO SCHISTOSOMIASIS RESEARCH AND CONTROL PROJECT AT THE VOLTA LAKE, 1971 - 1978

3.1 INTRODUCTION

The health component of the Volta Lake Research Project ended in 1973. The work by the unit drew attention to the need to control schistosomiasis at the Volta Lake and in other large man-made lakes. A year earlier, final agreement ahd been reached by the governments of Ghana and Egypt with UNDP to support a major WHO-run project on schistosomiasis at the Volta Lake. One main objective of the project was to conduct research on the ecology and epidemiology of S. haematobium in one section of the lake so that cost/effective ways of controlling the infection could be tested and evaluated. A second objective was to train Ghanaian and Egyptian personnel in the research and control methods developed. Project results were to be made available to the health authorities in Ghana and Egypt so that they could possibly implement those control measures which would be applicable to other parts of the Volta Lake and at Lake Nasser.

The scope and planned duration of the UNDP/WHO schistosomiasis project at the Volta Lake (herein referred to as the "WHO project" or "the project") was continually reappraised by UNDP, and it eventually ran for 7.5 years before it was officially handed-over to the Ghana Ministry of Health in December 1978.

As part of the introduction to this thesis, it is necessary to briefly review the project's activities and main results achieved. Unless specifically stated as otherwise, facts and figures cited in this section come from the final, unpublished project report of 1979[1], or unpublished WHO project data made available to all senior staff members.

Overall, the WHO project was successful in greatly reducing S. haematobium egg counts in an area of generally high endemicity. The thoroughness in which data were collected and computerized will serve as a model for future field studies. However, as in any pioneering field study, there were inevitable problems which hampered the project's design,

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1 Research on the epidemiology and methodology of schistosomiasis control in man-made lakes (RAF/71/217). Ghana and Egypt. Project findings and recommendations. UNDP/WHO, Geneva, 1979.

control effort, and evaluation of the results. It is hoped that highlighting some of these problems will benefit others engaged in research on schistosomiasis in a similar environment.

3.2 PROJECT DESIGN

3.2.1 Schedule of operations

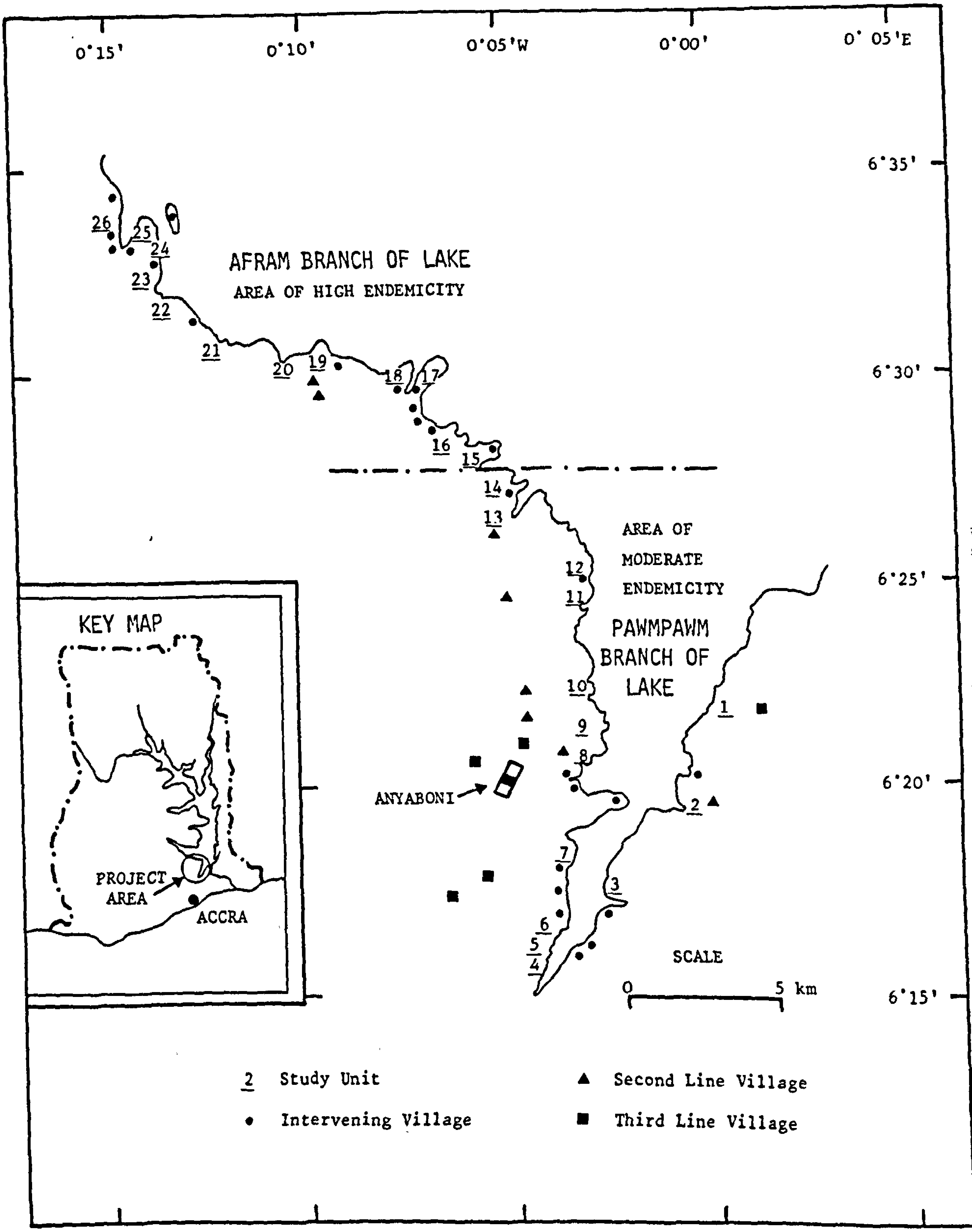
The original plan of operation (WHO document RAF/71/217, 1971) outlined a schedule of activities that was unrealistically short. The preliminary research phase was to last for 7 months, followed by a 12 month phase of baseline data collection, and a 12 month period of intervention and evaluation. However, yearly negotiations with UNDP resulted in the extension of each phase. The preparatory phase ran from mid 1971 to February 1973, collection of baseline data from March 1973 to May 1975, and the intervention and evaluation period from June 1975 to December 1978.

3.2.2 Teams, personnel, and facilities

Three research units with WHO personnel were established: (1) an epidemiology team consisting of Project Manager, Epidemiologist (1975 - 1978), and Technical Officer; (2) a biology team consisting of Senior Biologist, Junior Biologist (Scientist), and Technical Officer; and (3) a sociology unit of one Social Scientist. Each unit was supported by technical officers from the Ghana Ministry of Health as well as locally recruited staff.

During most of the intervention period, the project owned a fleet of up to 9 Landrovers, 5 Peugeot estate wagons, 2 Volkswagon minibuses, and 2 small cabin cruisers.

The project's headquarters and main laboratory were in Accra. The field station containing laboratories and living quarters was at the Anyaboni Resettlement Town, 125 km north of Accra, and 3 km by road to the nearest lakeside village (Map 5).



Map 5. Villages in or near study area of WHO project.

Plate 6. WHO project field base at Anyaboni, 1979.

Plate 7. Project boat at study unit 1 (Pawmpawmnya No. 1), 1973. The village was located just behind the sandy, exposed shore, and because of the openness of the shore and lack of weed growth, S. haematobium transmission was very low.

3.2.3 <u>Selection of study area and study units</u>

Statistical criteria by WHO (1971 Study Proposal, PD 72.3, Geneva) required that the research be conducted along a part of the lake where at least 5,000 people lived and which could be reached easily from a field base. Within that stretch of shore, a number of "study units" (fishing villages) were to be selected, each to have a population of between 100 and 400, and an <u>S. haematobium</u> prevalence rate of at least 45% among 2 to 12 year-old children.

The area selected was within a 60 km section of the shore - 10 km on the eastern bank of the Pawmpawm branch, and 50 km from the lower tip of the Pawmpawm branch on the western shore into part of the Afram branch as far north as 6° 35' (Map 5). Twenty-six villages which met the statistical requirements were selected to be study units. The study area (also called project area) was defined as only the area of shore occupied by the study units, excluding all settlements between them or behind them. In 1973, the first census enumerated 4,283 people in the 26 study units. By 1978, the population had decreased to 3,998.

When the research began, it was thought that the other lakeside villages and hamlets which existed between the study units would not pose any problem with data collection in the study area. However, it soon became apparent that there were more of these villages than originally thought. In 1977, Chu, Klumpp, and Kofi (1981) found 29 "intervening", lakeside villages between study units 1 and 26, with a population of 2,780 people. Two of the intervening villages were actually groups of households which were part of 2 respective study units but which were excluded because they were over 0.5 km from the main cluster of households. The same survey revealed another 14 villages behind the study units, 1 - 5 km from the lake ("second-line" and "third-line" villages). The population of these hinterland villages was approximately 8,000. These people also had considerable contact with the study units, and in a number of cases shared the same water contact points with the lakeside inhabitants.

3.2.4 <u>Change in study design</u>

The 1971 study proposal recommended that (after an initial prevalence survey) the study units should be divided by cluster into 5 epidemiological groups with similar ranges of prevalence rates. Epidemiological and malacological baseline studies were to be conducted in each epidemiological group, in those study units where prevalence rates were highest and lowest. During the intervention phase, single methods of control - chemotherapy, mollusciciding, and health education - were to be applied separately in 3 of the groups. Another group would receive a combination of 2 or more methods, and the 5th group was to be left as a comparison area. Data collection was to continue in all epidemiological groups for evaluation.

It soon became apparent, however, that it would be impossible to follow the above design and achieve any meaningful evaluation of the results of the intervention measures within the original, short time span of the project. Even after the phases of baseline data collection and intervention were extended, there were other reasons which necessitated a change of strategy. First, 11 of the 12 study units with highest prevalence rates and egg densities were located in the northwest end of the study area. To have met the statistical requirement of similar ranges in prevalence rates within each epidemiological group would have meant expanding the study population to approximately 12,000. This was beyond the resources of the project. Second, because intensities of cercarial transmission were so different within the study area, the 5 epidemiological groups would not have been comparable in terms of transmission potential. Third, the high degree of human migration observed within and outside of the study area, combined with the reservoir of infection in the intervening and hinterland villages, would have made it difficult, if not impossible, to evaluate the efficacy of the individual control measures.

3.2.5 New intervention strategy

In November 1974, the plan of having 5 epidemiological groups of villages was abandoned, and a new intervention strategy was chosen. Residents of all 26 study units found to be positive for *S. haematobium* were to be treated with a suitable drug once a year, all potentially dangerous water contact points in the study units would be mollusciciced whenever necessary, and 7 villages would be provided with water supply in the form of bore wells.

3.2.6 Strategy of chemotherapy

The selected drug for chemotherapy was metrifonate (Bilarcil). The strategy of delivery was "selective population chemotherapy" (SPC) - the treatment of people found to be positive for *S. haematobium*. SPC campaigns were carried out once a year from 1975 through 1978. At each SPC, metrifonate was given to all registered, present, and willing study-unit residents who were found to be positive in the most recent, prior epidemiological survey. Refusal of treatment was rare. The dosage of the drug was 7.5 mg per kg body weight, and it was delivered on 3 occasions at fortnightly intervals. Follow-up screening of all residents for *S. haematobium* took place roughly 6 months after each SPC. The method of examination was based on single, 5 ml urine samples (Scott, Senker, and England, 1982).

The efficacy of chemotherapy (helped with mollusciciding) was evaluated by pre- and postcontrol comparison of age-specific prevalence rates and geometric mean of egg counts among all sampled residents in the 26 study units. There were 2 full precontrol surveys (S2, 1973; S4, 1974) and 3 full postcontrol surveys (S6, 1976; S7, 1977; and S8, 1978).

3.2.7 Strategy of mollusciciding

The molluscicide used throughout the intervention period was a wettable powder of niclosamide (Bayluscide), 70% active ingredient. Early in the project it was learned that almost all transmission was confined to human water contact points. The strategy of mollusciciding was therefore to kill infected snails in WCPs rather than to aim at snail control *per se*. In order to achieve this goal, all WCPs in the study area (up to 230) had to be visited by the biology team every month, and in the most potentially dangerous WCPs, 3 times every 2 months. The decision to dose a WCP with niclosamide was made by the team during these site visits, on the basis of ecological criteria established by Chu (1978).

When it became necessary to molluscicide, it was done by technicians using Hudson X-Pert, knapsack sprayers, with a calculated amount of niclosamide to achieve a final concentration of 0.5 mg/l over at least a few hours. The aim was to achieve a quick kill near shore where most infected snails were concentrated. The chemical was usually sprayed from shore into a zone within 5 m from shore, and allowed to diffuse into deeper water. Where emergent vegetation was thin or absent, it was sometimes necessary to wall-off the estimated aquatic boundary of the WCP with plastic curtains to prevent rapid dilution of the molluscicide (Chu, ibid).

The efficacy of molluscciciding was evaluated by comparison of pre- and postcontrol baseline data of snail sampling. Sampling began in March 1973 and continued every month through December 1978. This included 28 - 33 WCPs in 10 study units in the Pawmpawm branch and 16 WCPs in 6 study units in the Afram section.

Since molluscciciding was focal, its application had no significant, detrimental impact on fish or invertebrates. This was confirmed by the Ghana Institute of Aquatic Biology, which carried out extensive sampling before and after molluscciciding in and around WCPs in 1975 (Odei, unpublished report to WHO project, 1976).

3.2.8 Strategy of water supply

In addition to chemotherapy and molluscciciding, 7 study units were provided with water supply in 1975 in the form of 13 drilled bore wells, 1 - 3 per village. Each pump unit was of the Canadian Monarch type, consisting of a simple standpipe with an outlet tap, and a pumping arm with a wooden handle. The pump base was supported by a concrete slab. The installation of the wells was performed by the Ghana Water and Sewerage Corporation. The purpose of installing the wells was to reduce human water contact, especially domestic chores like fetching water and washing. To strengthen the impact of the water supply, people in the 7 villages also received health education by the sociology unit.

3.2.9 Extension of control to the intervening villages

After control began, residents of study units were seen having water contact in untreated WCPs in the intervening villages. Chu and Klumpp (unpublished report to WHO Review Mission, 1977) carried out snail sampling in the main WCP of all intervening villages during March, April, and May 1977). Even though 8 of the 29 intervening villages (all in the Pawmpawm branch) had received some chemotherapy with either niridazole (Ambilhar) or metrifonate during 1975 and 1976 (part of drug treatment trials), the number and percentage of *B. rohlfsi* found with patent *S. haematobium* cercariae in the intervening villages was very high - 120 (15.9%) in the Afram section and 56 (18.2%) in the Pawmpawm section. The WHO Review Mission of June 1977 therefore recommended that beginning in July 1977, all intervening villages of highest transmission potential should receive mollusciciding on a monthly basis, plus selective population chemotherapy annually (after rapid, qualitative assessment by microscopy or haemoglobin-sensitive dip sticks).

3.2.10 Establishment of a comparison area

In 1975, W.R. Jobin (unpublished consultancy report to project) recommended that the project should establish a comparison area, because without it, the validity of the project's results would be in jeopardy, since there would be no way of verifying whether postcontrol reductions in the study area were achieved against a background of stable or changing levels of *S. haematobium* infection. This recommendation was adopted by the project in 1976. A 20 km stretch of the southern shore of the Afram branch was selected, the eastern end approximately 50 km from study unit 26. It contained 10 villages with an initial population of 1265 people. Starting in 1976, surveys on *S. haematobium* prevalence rates and egg counts were conducted yearly in all 10 villages. Snail sampling was carried out monthly in the 2 main WCPs of each village, starting in 1977.

3.3 RESULTS OF INTERVENTION

3.3.1 Reduction in number of infected snails

Detailed results of this work have been published (Chu et al., 1981). It can be seen from the summary results of baseline sampling (Table 4) that after 3 years of intervention, the number of infected snails was reduced by over 95%.

Plate 8. Technician spraying niclosamide into large WCP. Note plastic curtains in deep water boundary of WCP. This prevented rapid dilution of the molluscicide.

Table 4. Yearly number (June to May) of B. rohlfsi with patent S. haematobium cercariae during pre- and postcontrol periods. (From Chu et al., 1981.)

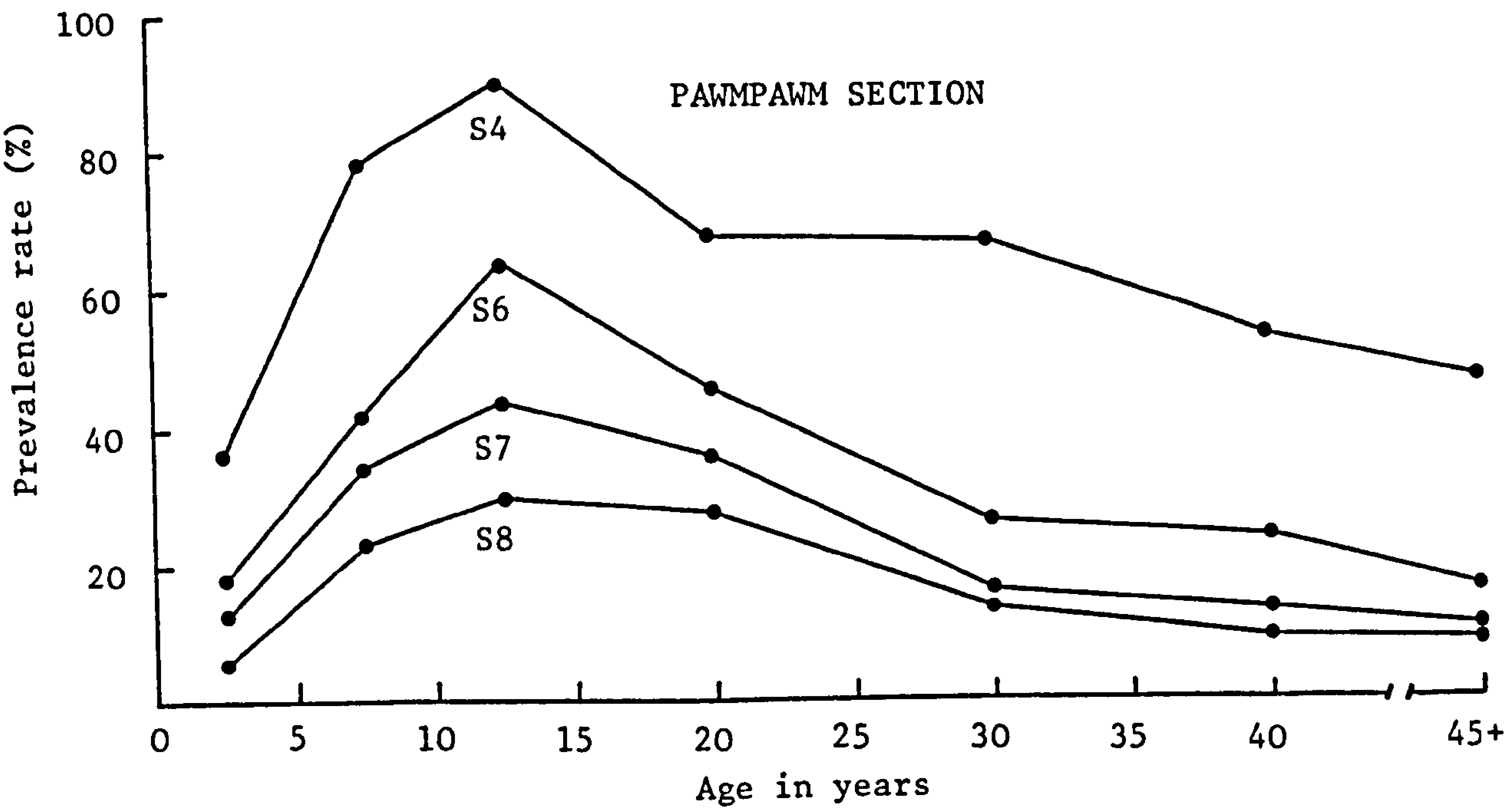
	Precontrol		Postcontrol		
	1973/74	1974/75	1975/76	1976/77	1977/78
10 Pawmpawm villages	83	38	6	1	1
6 Afram villages	228	166	8	2	2

The potential for transmission was much higher in the Afram branch than in the Pawmpawm branch. The main reason for this was that *Ceratophyllum* remained in, or increased to moderate to heavy density in all but one of the 12 total Afram study units between 1973 and 1978; in the same period, the weed largely disappeared from all study units in the Pawmpamw branch (Klumpp and Chu, 1980). Increasing density of the weed was positively correlated with increasing numbers of infected *B. rohlfsi* in WCPs, and increasing levels of *S. haematobium* infection in humans.

The reduction in numbers of infected snails during the second precontrol year was mainly due to the natural die-off of *Ceratophyllum* in the Pawmpawm branch and lake flooding of some compounds in the Afram branch which, in the latter area, caused a permanent cessation of human water contact at 2 important, sampled WCPs.

3.3.2 Reduction in prevalence rates

Age-specific prevalence rates before and after intervention are shown in Figure 1. Separate results are presented for people in study units 1 - 14 (Pawmpawm section; area of moderate endemicity) and in study units 15 - 26 (Afram section; area of high endemicity). Details of the precontrol findings have been presented by Scott et al., 1982).



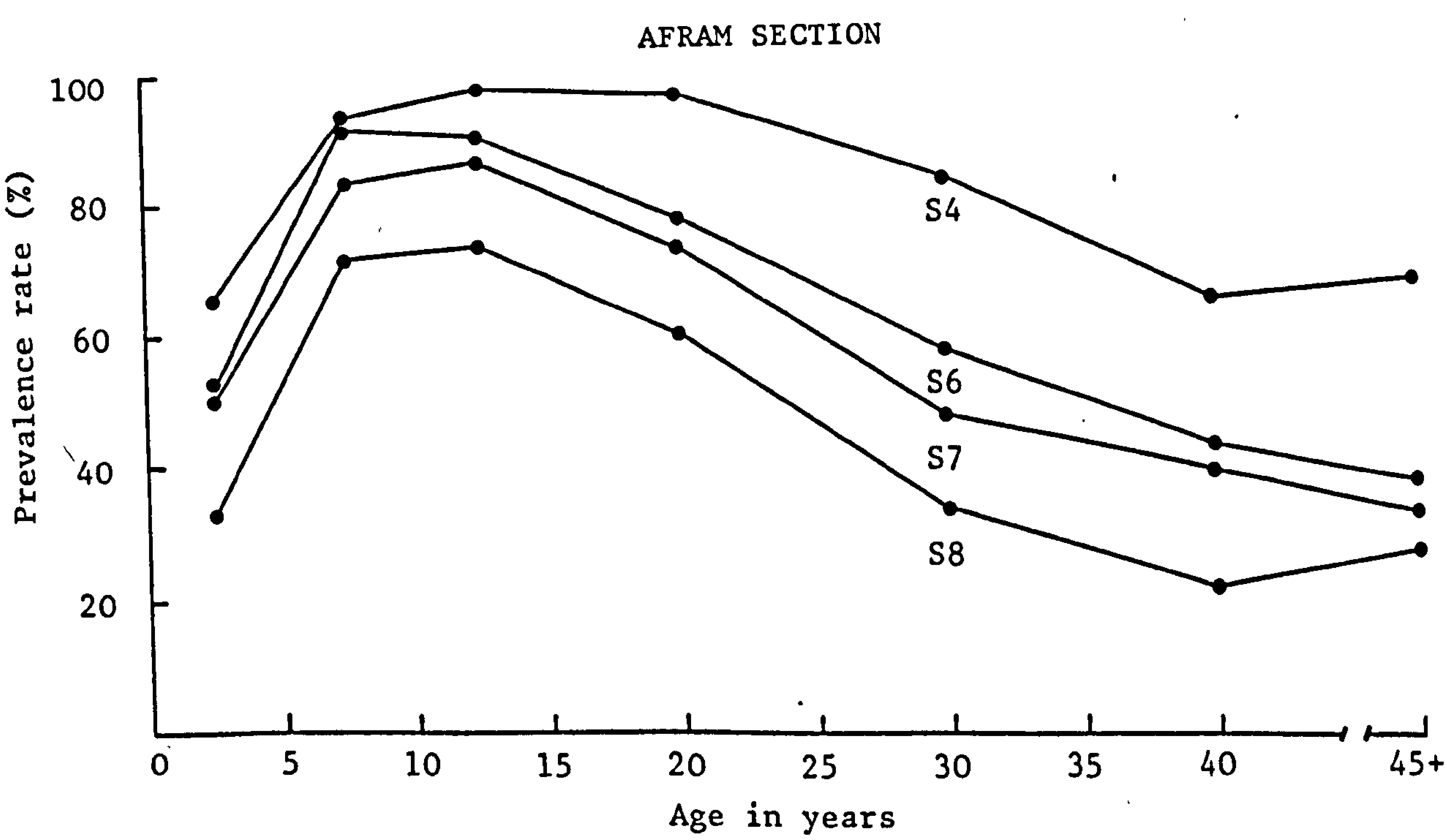


Fig. 1. Prevalence rates of S. haematobium in Pawmpawm and Afram sections of study area, at last precontrol survey in 1974 (S4), and 4 - 6 months after chemotherapy campaigns in 1976 (S6), 1977 (S7), and 1978 (S8).

After 3 years of intervention, the prevalence rate for all ages in the Pawmpawm study units was reduced by 72.3%, and by almost as much in the 10 - 14 year-old age group of peak infection. In the Afram section, the corresponding overall reduction was less impressive - 39.5%.

Precontrol egg counts of S. haematobium were considerable higher among people living in the Afram section vs. the Pawmpawm section. That was probably the main reason why comparable cure rates could not be achieved in the 2 sections. And unlike the study units in the Pawmpawm section which were located at the "closed end" of the study area, the study units in the Afram branch were at the "open end" of the study area, close to an untreated area of the lake of high endemicity. An additional large reservoir of infection initially existed in 15 intervening villages near the Afram study units.

The reason for the improvement in results in the 12 Afram study units in 1978 was probably due in part to an earlier follow-up of urine examination that year. On average, Survey 8 was conducted only 4 months after SPC 3 in 1978, compared with 6-month intervals following SPC 1 and SPC 2. Thus, the egg-suppressing and/or prophylactic effect of metrifonate in 1978 may have been greater. Moreover, during Survey 8, 22.7% of the Afram residents were temporarily absent from their villages and could not be examined. This group could have included a high proportion of positives. In 1976 and 1977, the percentage of these absentees was 8.3% and 15.4% respectively. The improvement in the 1978 results could have also been due to successful molluscicstep in the Afram study units and intervening villages between them. During 1978, all WCPs in these villages were sprayed 3 times every 2 months.

3.3.3 Reduction in egg counts

The most successful achievement of the project was the drastic reduction in S. haematobium egg output in every study unit. In both the Pawmpawm and Afram sections, the overall geometric mean egg count was reduced by at least 78% after 3 years of intervention. Results were almost as good in the age groups of peak infection (Figure 2).

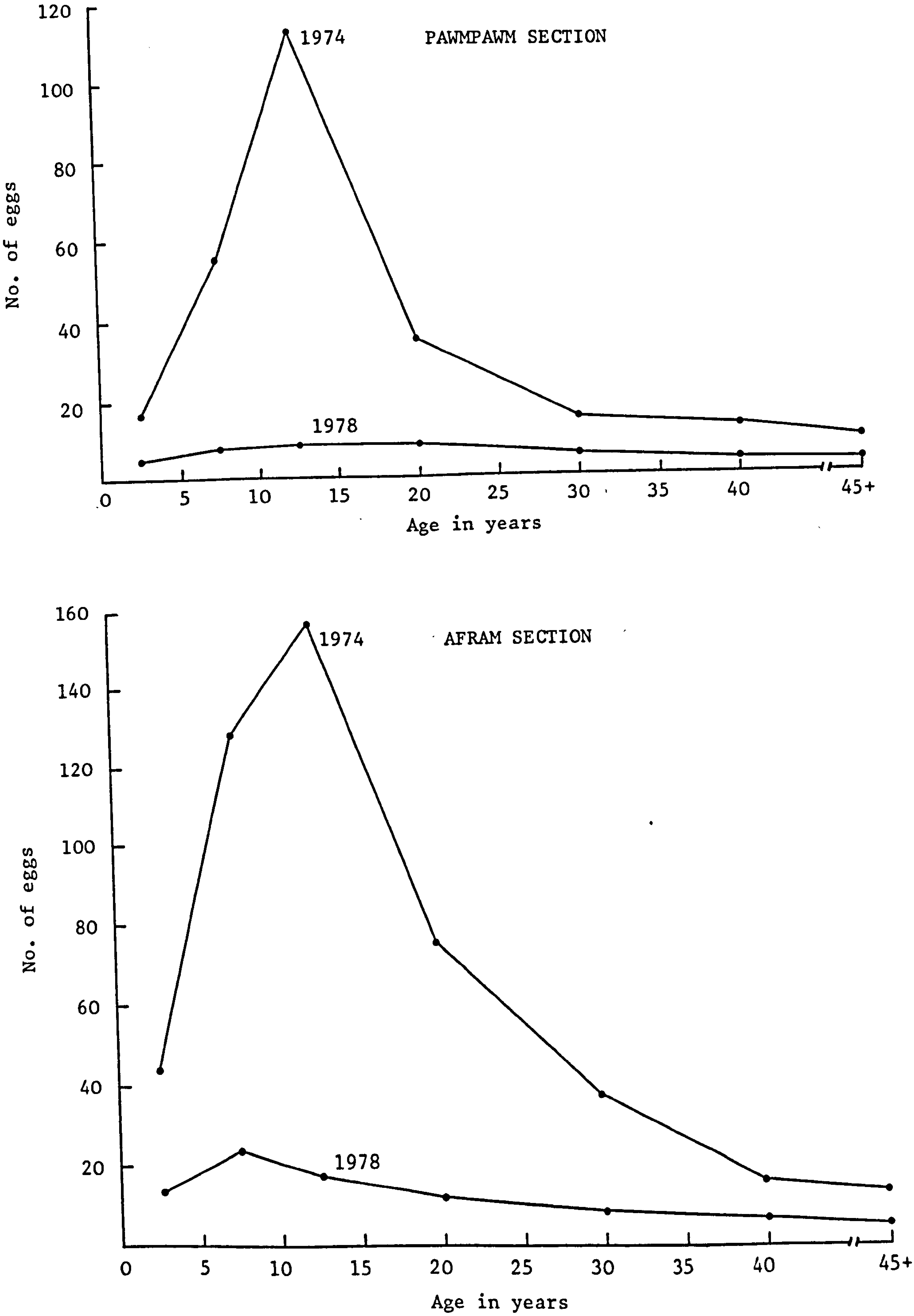


Fig. 2. Geometric mean of egg output (eggs/5 ml of positive urines) in Pawmpawm and Afram sections of study area, at last precontrol survey in 1974, and 4 months after final chemotherapy campaign in 1978.

3.3.4 Costs of the intervention measures

The final project report of 1979 listed the annual per capita costs for the 3 intervention programmes as follows: cercarial transmission control, $1.10; chemotherapy, $1.94; water supply (over 3 years), $8.53. Labour and transport costs contributed to 89% of the total expense for cercarial transmission control and 73% of the total cost for chemotherapy. Over 98% of the cost of water supply was for the purchase of bores and pumps plus drilling and installation charges.

As applied in the study area, all 3 intervention measures were too expensive for the Ghana Ministry of Health to adopt for eventual extension to other sections of the Volta Lake or to other parts of Ghana. Although not stated explicitly in the final project report, emphasis on future schistosomiasis control in Ghana was to be placed on chemotherapy alone (personal communication with Dr. E. Osei-Tutu, Head, Ghana Schistosomiasis Unit). Anticipating this, the report recommended that in addition to sustaining control of *S. haematobium* in the study area (for continuity of evaluation), the Ministry of Health should experiment with ways to simplify urine examination, and streamline the logistics of drug delivery (e.g., evaluating the cost/effectiveness of treatment based on a single dose of metrifonate at 10 mg/kg).

3.4 DISCUSSION: SOME PROBLEMS IN EVALUATING SUCCESS OF CONTROL RESULTS

3.4.1 Crude incidence rates

The 1973 WHO Review Mission recommended that longitudinal studies should be initiated in the study area to gather information on pre- and postcontrol incidence rates of *S. haematobium*. Only one such study was ever carried out in the precontrol period, from October 1974 to September 1975 (Scott et al., 1982). From the results (which involved all age groups), the estimated overall annual incidence rate was 46%. Absenteeism was so great in this longitudinal study that it was possible to examine urine from only about 40 - 70 people per month. Most of the cohort came from a few large villages in the Pawmpawm branch. In the Afram section, few children were ever negative for *S. haematobium*.

As one means of evaluating the efficacy of the combined intervention measures in the study area and the impact of water supply in the 7 study units, the final project report extracted "crude incidence" rates from computerized records of each person's egg counts between consecutive epidemiological surveys in the pre- and postcontrol periods. But were these data reliable for calculating incidence rates? Probably not. They were based on single 5 ml urine samples, and false positive and false negative results could not be discounted. In 1977, Chu and Senker (unpublished report to WHO Review Mission, 1977) traced 16 out of 31 children who were reported in the records to have converted from negative to positive between the final precontrol survey (1974) and the first postcontrol survey (1976). They collected and examined full bladder amounts of urine from all 16 children over 2 - 3 consecutive days. The urines were centrifuged and carefully examined microscopically for *S. haematobium* eggs. Confirmation of eggs was found in only 6 of the children; the remaining 10 were negative over the 2 - 3 day period.

This limited study raised the possibility that contamination sometimes occurred during the routine processing of urines in the field. One question mark of the method employed in the project was that only one automatic syringe was used in extracting the 5 ml sub-samples from urines when the sub-samples were injected in series into individual specimen bottles (containing a stain/fixative). Although Scott et al. (1982) stated that precautions were taken to minimize contamination (by rinsing the syringes between taking sub-samples), it is the opinion of the author that such contamination was possible when junior assistants were left to do the work, a frequent occurrence in the postcontrol period.

Another problem in trying to interpret the crude incidence rates from the survey records is in tracing where the infections were acquired. Was it mainly in the study units, or did a significant amount occur in the intervening villages, other sections of the lake, or for Ewes, during their frequent visits to their home towns in the Volta delta? Unfortunately, detailed data on inter- and intra-village movement by people in the study units were never obtained in the project.

3.4.2 Participation

Although repeated visits were made to the study units during SPC campaigns, and very few people refused treatment, there was a degree of absenteeism which left a significant reservoir of infected persons in the villages during the postcontrol period. The percentage of positives who received no treatment or incomplete treatment ranged from 18 to 33% (Table 5; from final project report, 1979).

Table 5. Participation levels during SPC campaigns.

Year*	SPC	Study area population	Positive for treatment	(%)	Level of treatment,% Full	Incomplete	None
1975	1	3232	2239	(69)	82	6	12
1976	2	3363	1651	(49)	67	11	22
1977	3	3488	1357	(39)	70	11	19
1978	4	3998	1019	(25)	71	12	17

* Follow-up surveys on prevalence rates and egg output conducted in the following year.

It is the opinion of the author that better levels of treatment could have been achieved if the chemotherapy team had worked during evening hours when village populations were at their peak. This was never tried in the project. As it was, the teams worked almost exclusively between 0900 - 1400 h. During these hours, villagers were often away at markets, at their farms, or fishing. In addition, more effort could have been made to notify the villagers of treatment in advance of the chemotherapy teams actually arriving. This was done consistently only in the 7 villages receiving water supply and health education. Participation levels in these villages during chemotherapy campaigns were 4 - 10% higher than in the "non water" villages.

Table 6 gives the percentage of people in each epidemiological survey who were examined, were newcomers to the study area, were absent temporarily from the villages, and who moved permanently from the study area (WHO project data).

Table 6. Levels of participation in surveys for prevalence rates and egg counts of S. haematobium.

			Percentage of the population			
Year	Survey	Study area population*	Examined	Newcomers	Absent temporarily	Moved permanently
1973	2	3480	72	12	17	27
1974	4	3253	87	4	8	13
1976	6	3359	89	14	6	13
1977	7	3473	82	11	14	5
1978	8	3998	73	25	25	0

* Slightly different population figures than presented in Table 5. Present figures from computer printout sheets, and included new births, people absent temporarily, old residents. People who died or moved permanently were part of the population at the last, prior survey.

Despite many follow-up visits to all study units, the percentage of residents who were not examined in the surveys ranged from 11 - 28%. Most of these people were absent temporarily - they had travelled to various places and would be returning shortly. The percentage of people who moved permanently from the study area was higher than the latter group until 1977; it then dropped to a low level. The newcomers constituted a large group in 1978. During postcontrol, 67 - 68% of the people who temporarily left the study area were positive for S. haematobium after their return, and 46 - 57% of the newcomers were positive. The overall range of prevalence rates for residents remaining in the study area during the postcontrol surveys was 34 - 52%.

The transitory population structure recorded from year to year is probably representative for the lake as a whole. It highlights the difficulty of sustaining control of schistosomiasis at the Volta Lake. Even with maximum effort directed at treating all known positives in a given area of the lake, as was attempted in the project, there will remain a dynamic reservoir of infected people who can cause a rapid recrudescence of S. haematobium infection once control measures are ended.

3.4.3 Water supply

The final project report of 1979 stated that ... "the provision of water supplies and the supporting community motivation programme contributed significantly to the reduction in transmission. However, many other factors besides the supply or non-supply of water influenced the results presented on the Pawmpawm, e.g., changing ecology, composition and stability of the population, so that it is impossible to state precisely the impact of water supplies".

The report compared the 5 "water" villages and 9 "non-water" villages at the Pawmpawm branch in respect to the percentage reductions in prevalence rates, geometric mean of positive egg counts, and crude incidence rates for all age groups between 1974 and 1978 (Table 7).

Table 7. Final postcontrol reductions of parameters of infection in water and non-water villages between 1974 and 1978.

	Villages with wells	Villages without wells
Prevalence rate	-75.6%	-68.0%
GM of + egg counts	-80.3%	-76.7%
Crude incidence rate	-63.6%	-72.9%

Although the data analysis was superficial and the crude incidence rates subject to error, the above figures show the equivocal impact of the wells in reducing S. haematobium transmission above and beyond chemotherapy and mollusciciding. It is the opinion of the author that the slightly better reductions in prevalence rate and egg counts in the water villages was more a reflection of the health education/community motivation effort in improving the thoroughness of metrifonate delivery than the effect of the wells in reducing human water contact.

The quality of the well water was poor. From 2 analyses of well water sampled carried out by the Ghana Water and Sewerage Corporation and one analysis by the author (following Standard Methods), the Most Probable Number of total and faecal coliform counts were close to 10^4 and 10^3 respectively. These counts were approximately the same as water samples collected from WCPs at the lake.

The concrete base of each pump unit was poorly constructed and there was no allowance for sanitary drainage around each well. This probably accounted for the high coliform counts in the well water samples. The well water was also consistently hard. The final project report acknowledged that women in some of the "water" villages preferred to do their washing in the lake.

For the first 3 years, the pumps held up against wear and tear. But after the project was transferred to the Ministry of Health, pump maintenance was relaxed. The author carried out monthly checks on the status of the wells from July 1979 to June 1980. In that period, only 2 of the original 13 wells continued to function properly each month. Five wells were either consistently dry or had broken down (Table 8; original data).

From the above, the lesson learned is the same as what Jordan et al. (1978) described for St. Lucia - that only a properly designed and maintained water supply, not simple wells or standpipes, will have lasting effect on the reduction of transmission of schistosomiasis. For the Volta Lake, a properly designed water supply should be reserved for large, stable villages or towns, not small, semi-nomadic fishing villages.

Plate 9. One of three broken WHO project wells at Akokoma, 1980.

Plate 10. Remains of WHO project well, Kasa, 1980.

Table 8. Monthly status of condition of wells in 7 study units, July 1979 - June 1980.

Village	No. of wells	Number of different months that: All wells functioning normally	Some wells functioning normally	All wells dry or pumps broken
Kponyo Kope	1	2	10	0
Fatem	2	0	0	12
Kasa	1	2	0	10
Poakwe Pawm.	2	0	12	0
Akokoma	3	0	0	12
Akotui West	1	12	0	0
Akatri	3	0	11	1

3.4.4 Comparison area

The 1979 final project report stated that the comparison area "was initially similar to the Study Area, particularly to the condition in its Afram villages".

In fact, levels of transmission and infection of S. haematobium were in a phase of natural decline in the comparison area, and this area had an ecology different from any other lake section.

There was initial similarity between the comparison area and the Afram section of the study area only in respect to initial, precontrol prevalence rates (Table 9; from final project report, 1979).

Table 9. Comparison of precontrol prevalence rates between villages in the study area and comparison area.

Area	Precontrol prevalence rate (%); all ages					% change
	1973	1974	1976	1977	1978	
						1973/74
14 Pawmpawm villages	65.4	64.6				- 1.2
12 Afram villages	80.4	83.9				+ 4.3
						1976/78
10 comparison area villages			80.1	75.3	73.5	- 8.2

The geometric mean of positive egg counts in the comparison area between 1976 and 1978 resembled the precontrol figures from the Pawmpawm villages, and showed a similar natural decline (Table 10; from final project report, 1979).

Table 10. Comparison of precontrol geometric mean egg counts between villages in the study area and comparison area.

Area	GM of positive egg counts (per 5 ml); all ages					% change
	1973	1974	1976	1977	1978	
						1973/74
14 Pawmpawm villages	41.6	33.1				- 20.4
12 Afram villages	70.2	65.4				- 6.8
						1976/78
10 comparison area villages			45.1	55.4	34.9	- 22.6

The decrease in precontrol egg counts in the Pawmpawm section coincided with an area wide die-off of Ceratophyllum which led to lower transmission. The natural decrease of egg counts in the comparison area was largely a consequence of the opposite happening - transmission reduced by water pollution, caused by an overabundance of decaying Ceratophyllum.

All 10 comparison area villages were located in the flat, southern end of the Afram Plains, 2 - 8 km from the steep escarpment of the Kwahu Ridge. From observations made by the author, the mean horizontal change in location of WCPs across the drawdown area each month (due to lake level fluctuation) was approximately 3 times that in the study area. Rainfall atop the forested ridge was higher than anywhere in the study area - averaging over 1500 mm per year. Discharge of nutrients and organic matter from the escarpment into the littoral zone of the comparison area produced zones of emergent weeds, floating Pistia, and offshore Ceratophyllum that were more extensive than in any other lake section.

After 1976, the lake level dropped steadily, and this shifted the offshore Ceratophyllum masses close to shore. The water pollution resulted when the weed was stranded in shallow water. WCPs were often temporary, cleared points within the dense weed mass during most months of 1977 and 1978. Populations of B. rohlfsi contracted in this unfavourable habitat.

After 1976, weed growth in the comparison area forced residents to reduce their contact with the lake, especially swimming and playing. Canoes had trouble penetrating the weed mass and women continually selected new, clean areas along the shore for fetching water. The combination of the shifting shoreline, decreasing snail populations, and reduced water contact led to significantly lower numbers and percentages of infected snails than in the heavily-infested Afram section of the study area; even the lightly-infested Pawmpawm section yielded higher values for these indices (Table 11; original data).

Table 11. Comparison of precontrol numbers and percentages of *B. rohlfsi* (infected with patent *S. haematobium* cercariae) between sampled villages in the study area and comparison area.

	Study area (1973-75)		Comparison area (1977-78)
	6 Afram villages*	10 Pawmpawm villages*	10 villages*
Mean no. of infected snails per sampled WCP	1.46	0.27	0.24
Snail infection rate	9.1%	6.4%	3.9%

* For best comparability, results are from 2 main WCPs per village.

The relatively low cercarial transmission potential in the comparison area during 1977 and 1978 might have accounted for the corresponding natural reduction in human prevalence rates and levels of egg output. As will be shown in chapter 7, levels of cercarial transmission in and around the comparison area during 1979 and 1980 were low in respect to other snail-infested sections of the lake studied.

In terms of population movement, there was more absenteeism in the comparison area than in the study area. Seventy-five percent of the comparison area residents were semi-nomadic Ewe fisherfolk; in the study area, this group made up only about 45% of the population. The Ewes in the comparison area depended much more on fishing for their livelihood than Ewes in the study area who supplemented fishing with farming. During 1976, 1977, and 1978, the lake dropped to its lowest post-impoundment levels, and fish yields dropped accordingly. In this period, 17.1% of all comparison area residents moved permanently, and 27% were absent temporarily during prevalence surveys. The percentage of newcomers was only 6.3% (Table 12; WHO project data).

Table 12. Comparison of participation levels in surveys for prevalence and egg output between people living in the comparison area and residents of the study area.

		Percentage of registered population		
Area	Period	Newcomers	Moved permanently	absent temporarily
26 study area villages	1976/78	10.2	14.5	11.6
10 comparison area villages	1976/78	6.3	17.1	27.0

Plate 11. Sampling for B. rohlfsi amid decaying mass of Ceratophyllum in temporary WCP at Abrobesua, comparison area, 1977.

Plate 12. Paddling canoe through dense Ceratophyllum at main WCP of Bekoe A, comparison area, 1977.

CHAPTER 4

DEVELOPMENT OF RELEVANT SNAIL SAMPLING METHODS FOR THE LAKE, AND SOME IMPORTANT ECOLOGICAL FINDINGS ON *B. ROHLFSI* FROM THE UNDP/WHO SCHISTOSOMIASIS PROJECT

4.1 INTRODUCTION

Part of the present study of the transmission of S. haematobium in different parts of the Volta Lake was to compare and contrast snail sampling results with earlier findings from the WHO project. In order to understand the choice of the snail sampling method used in the present research, it is necessary to describe the development of the snail sampling methods used in the WHO project. It is also relevant to review some of the project's findings on the physical ecology of water contact points, and how this influences the seasonality, focality, and intensity of cercarial transmission in the lake.

4.2 DEVELOPMENT OF SNAIL SAMPLING IN THE WHO PROJECT AREA

4.2.1 Available techniques

Hairston et al, (1958) evaluated direct and indirect sampling techniques for estimating snail populations. Direct methods included collecting snails after (1) exhaustive removal of pieces of habitat, (2) removing small areas of habitat bottom by tube sampling, (3) removing areas of habitat with grabs, (4) scraping out areas of habitat bottom with drag scoops, (5) placing metal quadrats in muddy or weedy bottom areas of semi-terrestrial habitats, (6) dipping nets or sieves in the water a given number of times, and (7) searching directly for snails with forceps and sieves over a fixed period of time (man-time method)

Indirect sampling methods included (1) placing marked snails in a habitat and estimating populations in a later visit (from total snails collected multiplied by the total number marked, divided by the number retaken), and (2) using palm-leaf traps to collect snails qualitatively.

Modifications or additions of the above techniques have been described by many field workers, including Webbe (1960, 1962), Crossland (1962), Garnett and Hunt (1965), Prentice and Ealden (1971), Magendantz (1972), Chu and Vanderburg (1976), and Klumpp and Chu (1977).

4.2.2 Sampling techniques found unsuitable for the Volta Lake

During the preliminary phase of the WHO project, some of the above direct sampling methods were considered and tested. Drags and suction devices could not be used because the bottoms of water contact points were often full of tree stumps, fish nets, and dense weed growth. An Eckman grab and Emery dredge were tested but were found to be extremely impractical and inefficient. After collecting about 700 samples with the grab and dredge in water between 1 and 7 m deep, Chu and Vanderburg (1976) reported finding only 1 living B. rohlfsi.

4.2.3 Some problems associated with sampling for B. rohlfsi in the lake

Other factors added to the difficulty of snail sampling in the lake. First, in most study-area WCPs, the density of B. rohlfsi was generally low. It was rare to collect over 100 specimens in 1 man-hour of searching, or from over 30 palm-leaf traps. Being a small snail (the maximum shell height of wild specimens was 10.0 mm), it was even more difficult to collect young specimens and egg masses. When found, these were virtually indistinguishable from sympatric B. forskalii.

Second, except within a few metres from shore, B. rohlfsi was not a bottom dwelling snail; it preferred the shelter and phytoplankton provided by emergent plants, sticks, logs, or Ceratophyllum (Dazo and Biles, unpublished WHO report, 1972; Odei, 1972; Klumpp and Chu, 1977). Snail distribution was therefore clumped, associated with the distribution and density of emergent, floating, or dead macrophytes.

Third, it was impossible to take samples of the same populations of B. rohlfsi each month because of the continuous fluctuation in lake level. Figure 3 shows the vertical change in lake level each month, from 1973 to 1978).

In the WHO study area, the distance from the shoreline to a fixed marker on high ground was measured each month at the main WCP in 8 villages. Figure 4 shows the mean horizontal distance of the WCP shorelines between consecutive months, from March 1973 to May 1975 (original data). The mean monthly shifts ranged from 4 - 50 m. In every village, sampling areas rarely overlapped from month to month. Greatest changes occurred during periods of lake rise.

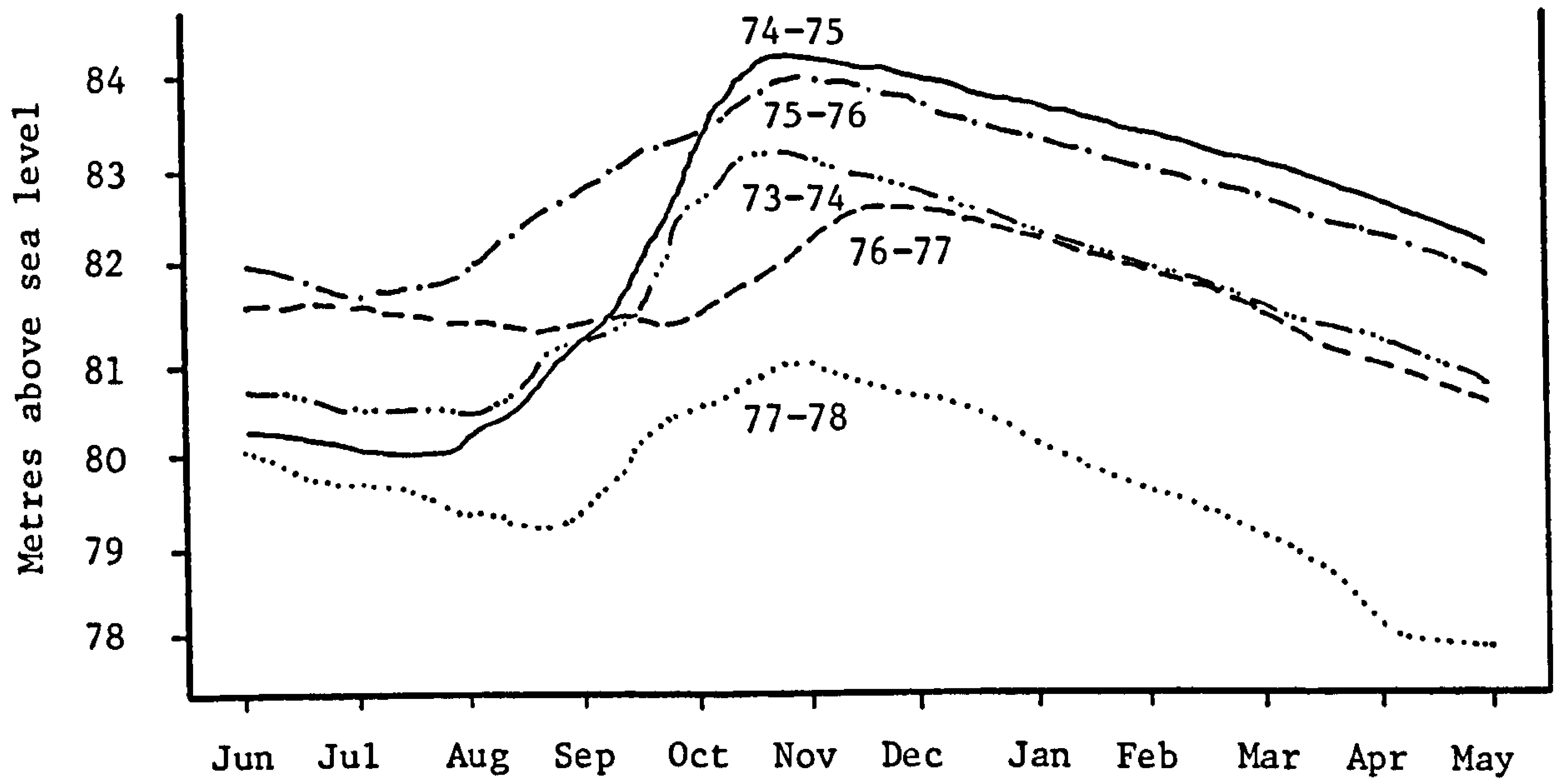


Fig. 3. Fluctuation in lake water level between 1973 and 1978 (from Chu et al., 1981).

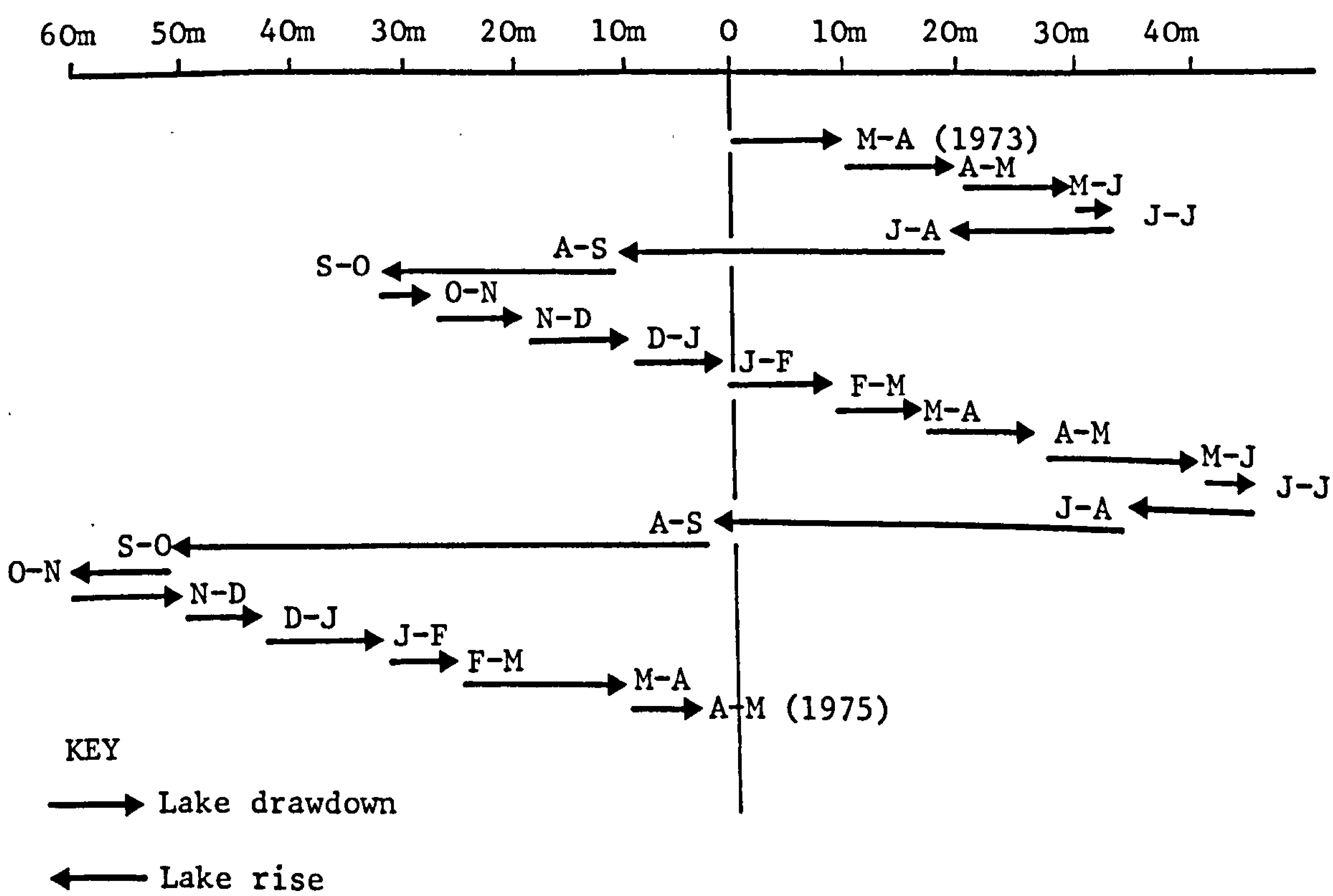


Fig. 4. Mean horizontal distances in metres that 8 main water contact point shorelines moved across drawdown areas between consecutive months, March - April 1973 to April - May 1975.

Not only did snail sampling involve taking samples from different areas, and presumably, different snail populations, it was also discovered that there was considerable passive migration of B. rohlfsi into WCPs (Jones, 1973; Chu, 1978; Klumpp and Chu, 1980). The snails were frequently blow-in on Ceratophyllum fragments from offshore masses, and occasionally carried-into WCPs by returning canoe fishermen - either in Ceratophyllum entangled in their nets, or when the weed was used to cover their fish in canoes.

Because of the ecological instability in the lake's littoral zone, ridgid, fractional sampling methods could not be used for collection of baseline data in the WHO project. A flexible technique was needed, one that would maximize the collection of infected snails in WCPs, so that some measure of cercarial transmission potential could be monitored quantitatively from month to month. Throughout the WHO project, two such flexible sampling methods were used: (1) standardized palm-mat sampling and (2) man-time sampling.

4.2.4 Development of the palm-mat sampling method

Azim and Ayad (1948) and Marill (1958) described how palm branches were effective traps for detecting the presence of Bulinus spp. in irrigation canals in the eastern Mediterranean and Algeria respectively. Hairston et al. (1958) mentioned the potential of palm traps for quantitative sampling if standardized. In 1972, L. Olivier, WHO, Geneva, recommended use of standardized palm-leaf traps for sampling in the Volta Lake (Chu, personal communication). This idea was followed-up by Chu and Vanderburg (1976) who designed, tested, and evaluated such standardized traps for collecting B. rohlfsi in the WHO study area.

The traps, or palm mats, were made of fresh oil palm leaves, woven through parallel rows of nylon string within a square frame of sliced palm branches measuring 45 cm per side.

Trials with the palm mats were so successful in collecting B. rohlfsi in varying ecological types of WCPs, it was decided to use them for baseline sampling.

The rationale for their use was as follows: (1) the traps could be used in the unstable habitat of the lake shore where the size, shape, and vegetation of WCPs could change significantly each month; (2) the area sampled would be the same each month; (3) the duration of sampling could be standardized; (4) oil palm leaves were abundant in the area; (5) the traps were more sensitive in collecting B. rohlfsi in deep water than man-time sampling; and (6) the mats could be placed on the lake bottom, or at any depth, wedged inside vegetation by using appropriate weighting stones or floats.

When baseline data collection began in March 1973, the palm mats were used for monthly snail sampling in 8 study units - 6 in the Pawmpawm branch and 2 in the Afram branch. The same number of mats were used in each sampled WCP each month. In all 8 villages, they were placed in the 2 most heavily-used WCPs, and in 1 - 3 additional WCPs, depending on village size. The number of mats placed in the most heavily-used WCP of each village ranged from 30 - 43; in the second main WCP, from 10 - 15; and for the lesser-used WCPs, from 5 - 10.

After placement, the palm mats were left in the water for 2 days. They were then carefully retrieved and immediately examined for snails. B. rohlfsi of 3 mm shell height or greater were placed in collecting bottles and labelled according to location within the WCP. Smaller specimens were returned to the water.

4.2.5 Development of the modified man-time sampling technique

During the first year of baseline data collection, it became clear that the above 8 villages did not represent the full range of ecological conditions in the study area, especially in the northwestern part where human prevalence rates and egg counts were highest. Thus, in Januray 1974, another 8 study units were chosen for expanded snail sampling. Four were in the Afram section and 4 were in the Pawmpawm section.

Because sampling with palm mats required extra manpower (for obtaining palm leaves and assembling the traps) and time (2 trips to a village required in 2 days), this technique could not be used for sampling in the second 8 villages, 5 of which were over 20 km from the Anyaboni field base. In these villages, snail sampling had to be carried out by a more rapid procedure.

Plate 13. A palm-leaf trap about to be lowered into a WCP containing Ceratophyllum.

Plate 14. Close-up of underside of palm-leaf trap just removed from a WCP. Note one B. rohlfsi clinging to leaf nearest anchoring stone.

The sampling method chosen was the man-time method, developed by Olivier and Sneidermann (1956). However, the method had to be modified slightly for sampling in the Volta Lake. Like Olivier and Sneidermann's method, sampling in the early drawdown and low water periods of the lake cycle involved men in thigh boots searching for snails with sieves in shallow water over a fixed period of time. But in the rising water period, it was necessary to change the procedure so that at least 2 men used chest waders or canoes (always available in the WCPs) to search for snails in deeper water, often pulling up vegetation by hand. As practiced in the WHO project, 4 men, each equipped with waders, sieves, rubber gloves, forceps, and collecting bottles hand searched for *B. rohlfsi* in WCPs for 15 minutes (one man-hour of sampling). Two men were stationed in individual areas within 5 m from shore, and 2 men sampled in individual areas in deeper water (about 5 - 10 m from shore during lake regression, and about 10 - 15 m from shore during lake rise).

4.2.6 Crushing and examining *B. rohlfsi* for *S. haematobium* cercariae

Snails collected from sampled WCPs were examined within a few hours at the Anyaboni field laboratory. All snails were individually measured, crushed between 2 glass slides, and examined under a dissecting microscope for evidence of trematode infection. Patent (mature) *S. haematobium* cercariae were easy to distinguish from other trematode cercariae. Very few bifurcated cercariae other than *S. haematobium* were ever encountered, and these were readily distinguishable by difference in morphology and "wiggling" action. *S. bovis* was absent from the area (no cows were kept in the study units or intervening villages). The main type of single-tailed cercariae were xiphidiocercariae, encountered about one fifth as often as *S. haematobium*. When *S. haematobium* cercariae were detected in a crushed snail, the soft snail parts were carefully teased apart and counts made of mature, active cercariae (usually performed by the author).

4.3 HOW WATER CONTACT POINTS ARE SHAPED AND CHANGE IN ECOLOGY

The inter-relationship between lake level, vegetation growth, and the shaping of WCPs was discussed in detail by Klumpp and Chu (1977). They classified 11 different types of WCPs.

Type 1 - Open beach beach without aquatic weeds.
Type 2 - Open beach with light to moderate aquatic weed growth.
Type 3 - Open beach with heavy aquatic weed growth.
Type 4 - Pocket-shaped without aquatic weeds.
Type 5 - Pocket-shaped with light to moderate aquatic weed growth.
Type 6 - Pocket-shaped with heavy aquatic weed growth.
Type 7 - Short channel (<30 m long) cut through emergent weeds.
Type 8 - Long channel (>30 m long) cut through emergent weeds.
Type 9 - Open beach at narrow stream inlet without aquatic weeds.
Type 10 - Open beach at narrow stream inlet with light to moderate aquatic weed growth.
Type 11 - Open area at shore, surrounded by emergent weeds, offshore, with narrow outlet channel to deep, open water.

During each year of sampling in the WHO project, the lake began to rise in July, and its level rose rapidly in September and October, before peaking in early November. In this period, a solid zone of emergent vegetation grew in the lake's littoral zone in most study units, and surrounded most WCPs. The dominant emergent species was *Polygonum senagalense*. It could maintain its foliage above water from shore to a depth of about 2 m, and where the drawdown slope was gradual, often grew in a solid zone for over 100 m from shore to its deep water limit. From September to November, human water contact was almost entirely confined to WCPs, due to emergent weed growth on the sides of the WCPs. In this period, WCPs were mainly shaped as narrow channels or type 11 WCPs.

After the lake reached its November peak, it receeded steadily each month until the following July. From December to March, most WCPs were still within the emergent plant zone, but as the zone narrowed, the WCPs became more open, and were mainly pocket-shaped.

From April to July, almost all WCPs had receeded beyond the former offshore limit of the emergent weed zone and became points on bare shores. In this period, human water contact was not as focal as when WCPs were totally or partially surrounded by emergent plants, but observations in the WHO project by Dalton and Pole (1978) revealed that it was still mainly confined to well defined points where footpaths led into the lake.

Plate 15. Rooted emergent plants and floating Ludwigia stolinofera growing in littoral zone at high water period of yearly lake cycle and preventing much human water contact outside of WCPs.

Plate 16. Solid zone of Polygonum senagalense growing around WCP shaped as a short channel during high water period.

Plate 17. WCP shaped as a long channel at high water period.

Plate 18. Type 11 WCP. Entire WCP is surrounded by weeds, but with a narrow passageway through offshore emergent weeds to open, deep water.

Plate 19. Pocket-shaped WCP (type 5) during early to mid-drawdown season.

Plate 20. Open beach WCP (type 1) during low water season.

From the observations of lake-level fluctuation and corresponding emergent weed growth in the littoral zone, Klumpp and Chu (1977) concluded that there were 3 main "lake seasons" of ecological significance during each annual lake cycle: (1) The rising water phase (August to October); (2) the early to mid-drawdown phase (November to March); and (3) the late drawdown phase (April to July).

4.4 SEASONALITY OF CERCARIAL TRANSMISSION

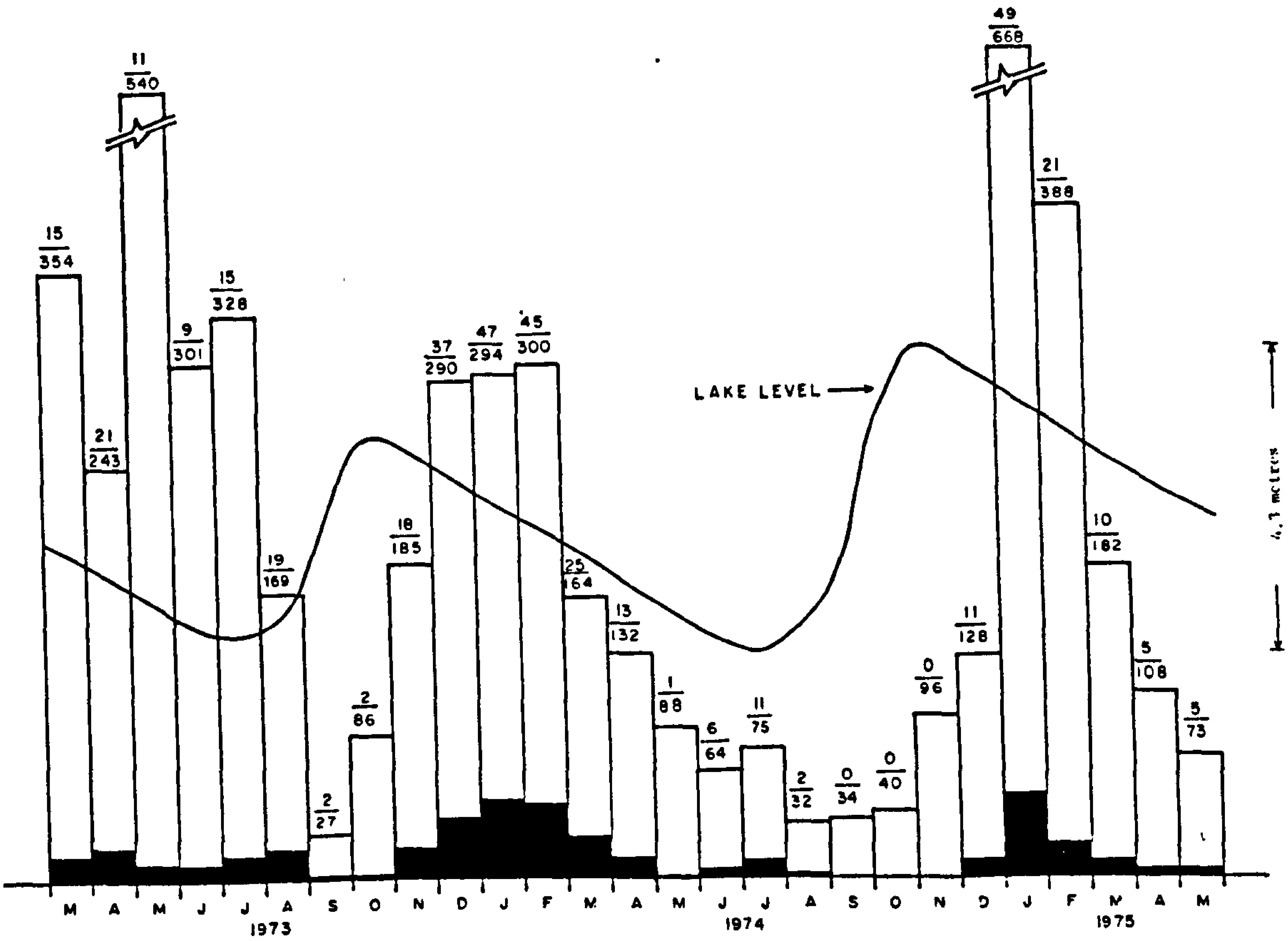
One important finding from snail sampling in the WHO project was that *S. haematobium* transmission in the study area seemed to be distinctly seasonal. This was later confirmed in the longitudinal study of human incidence rates by Scott et al. (1982). The overall precontrol snail sampling results in the first and second 8 villages are shown in Figure 5. Except for March - August 1973 (when *Ceratophyllum* was widespread in the Pawmpawm branch), total numbers of infected snails were highest in each early to mid-drawdown phase, generally low in the late drawdown phase, and very low in the rising water phase.

4.5 FOCALITY OF CERCARIAL TRANSMISSION

Another important finding from the WHO project was that, within WCPs, infected snails were concentrated close to shore (Chu and Klumpp, 1978). In one experiment at the main WCP at Akotui West, parallel rows of palm-leaf traps were placed at 1, 4, 7, 10, 13, 15, and 19 m from shore, once a month for 27 consecutive months. This WCP contained the greatest number of *B. rohlfsi* in the study area and changed least in shape and position during the annual lake cycle. At the end of this precontrol sampling, 88% of all infected snails were found within 10 m of the shoreline (Figure 6). Similarly, in all the WCPs sampled by man-time searching, 74% of all infected snails (and 63% of total snails) were collected within 10 m from shore (Klumpp and Chu, 1977).

Paperna (unpublished report to Ghana Ministry of Health, 1967) observed that snails infected with *S. haematobium* were confined to populated areas of the lake. Klumpp and Chu (1977) and Chu and Klumpp (1978) concluded from regular but non-systematic sampling that very few

First 8 villages: palm-mat sampling



Second 8 villages: man-time sampling

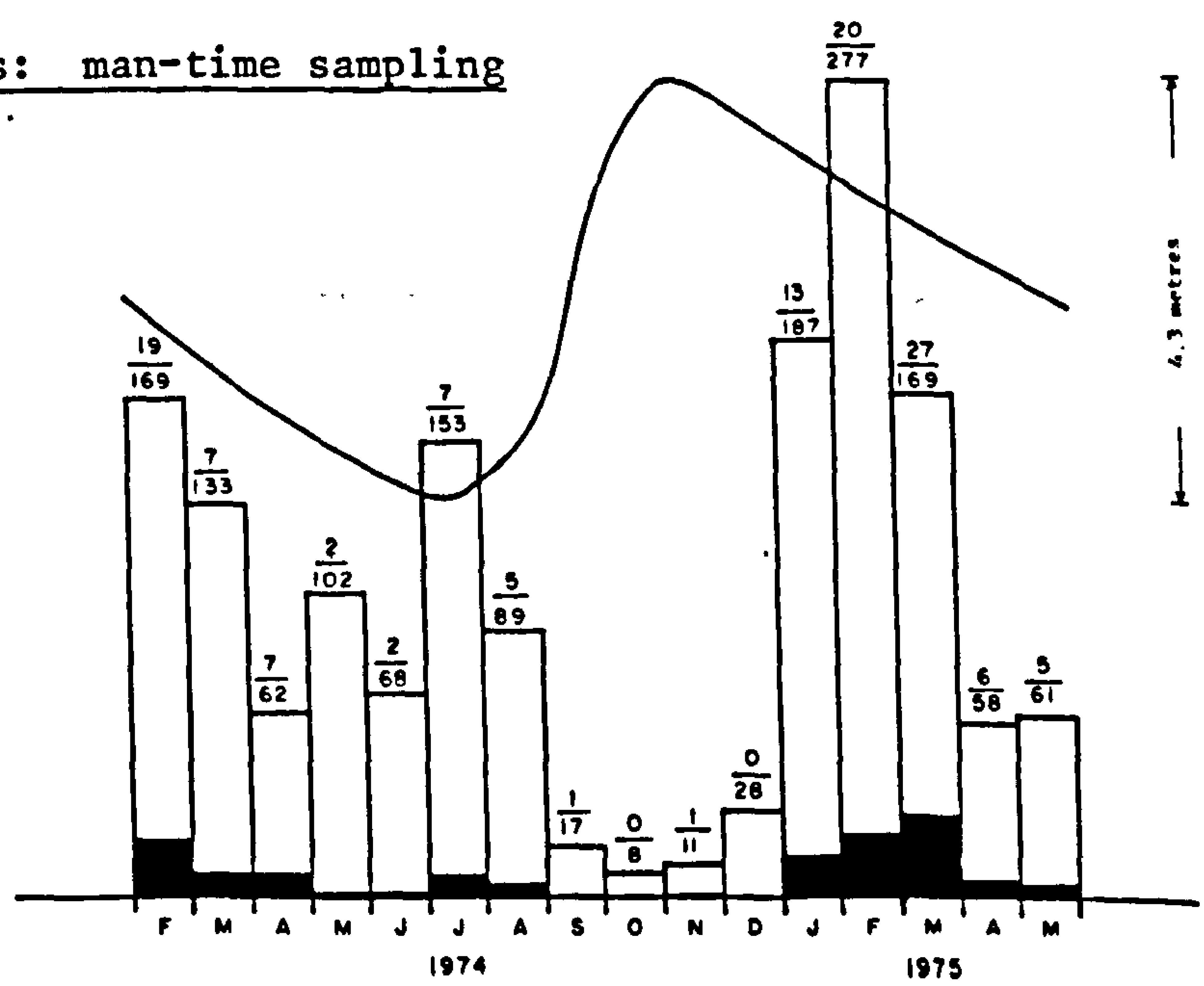


Fig. 5. Numbers of snails caught (open columns) and numbers of infected snails (black columns), by month, in relation to lake level: first and second eight villages.

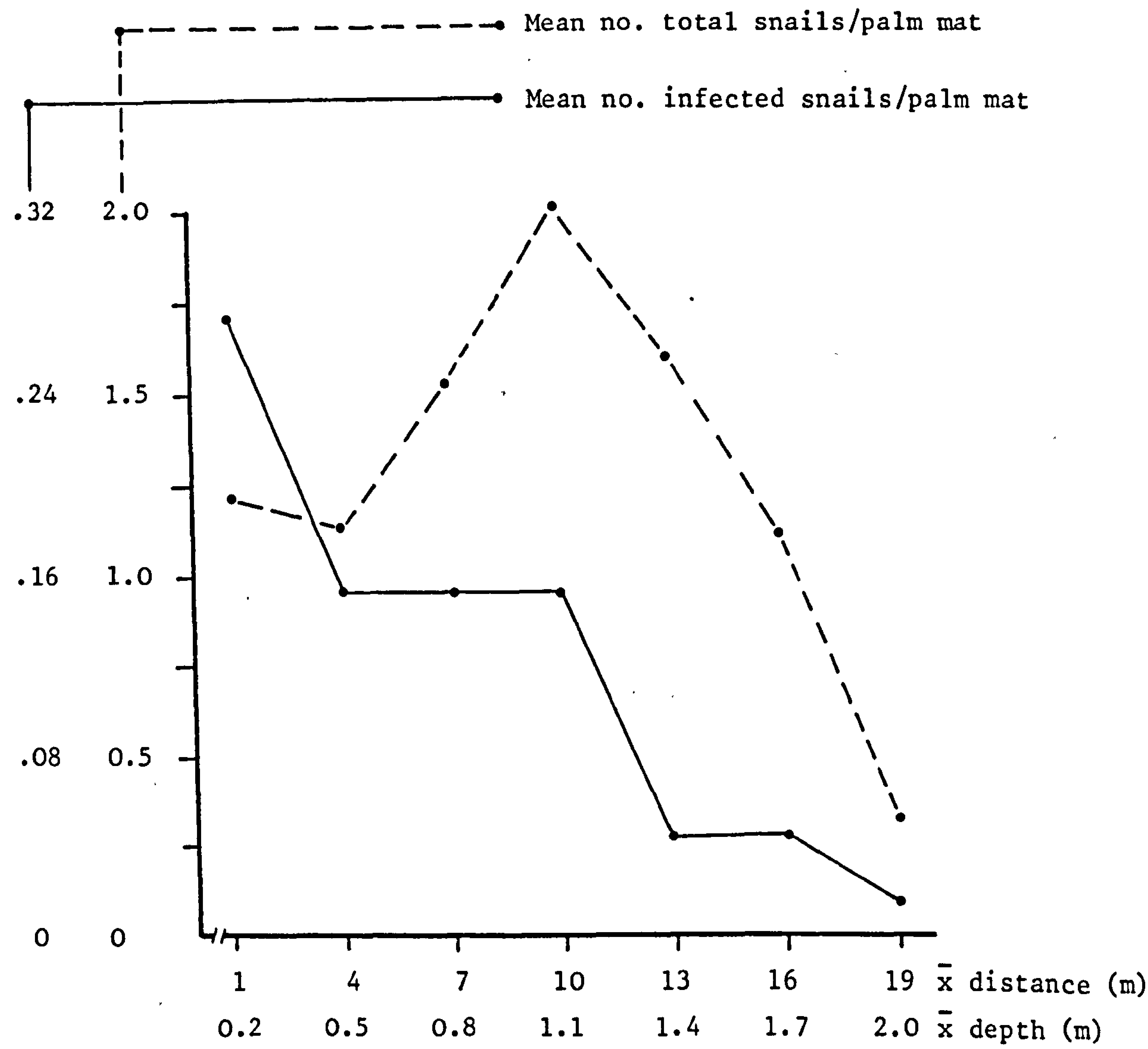


Fig. 6. Mean number of total B. rohlfsi and infected B. rohlfsi per palm-leaf trap, by average distance and depth from shore, 1973 - 1975 (from Chu and Klumpp, 1978).

infected snails could be found outside of WCPs. In light of recent evidence, however, the latter conclusion may not always be correct. From snail sampling by the author at Agbenoxoe (section 9.2.2) infected B. rohlfsi were collected along the entire length of shore in the village during a 6 month period of exhaustive sampling in 1980. But in terms of mean number of infected snails per metre of shoreline sampled at Agbenoxoe, the "density" of infected snails was 4 times greater inside of WCPs than away from them.

4.6 IMPORTANCE OF CERATOPHYLLUM TO TRANSMISSION

During the precontrol period of baseline sampling, 68% of all B. rohlfsi collected in the villages sampled by palm mats came from sections of WCPs where the traps were placed on or near Ceratophyllum. By man-time sampling, 84% of all snails collected were picked directly from the weed (Klumpp and Chu, 1977).

Later analysis of baseline data (Klumpp and Chu, 1980) revealed that a positive correlation existed between the overall mean Ceratophyllum density rank in sampled WCPs and the overall percentage of these WCPs that contained one or more infected B. rohlfsi (even though this relationship took the shape of an "s-shaped" curve; Figure 7).

Figure 7 reveals that the potential for transmission increased rapidly after Ceratophyllum exceeded a mean density rank of about 1.5 on a scale of 0 - 3. However, from snail sampling in the comparison area and results presented later in this thesis, it can be presumed that the potential for cercarial transmission would drop again if Ceratophyllum density rank remained over 2.3 or so for many months, due to the following chain of events which would occur: (1) the weed would decay in shallow water; (2) this would cause water pollution; and (3) this would kill B. rohlfsi and significantly reduce human water contact.

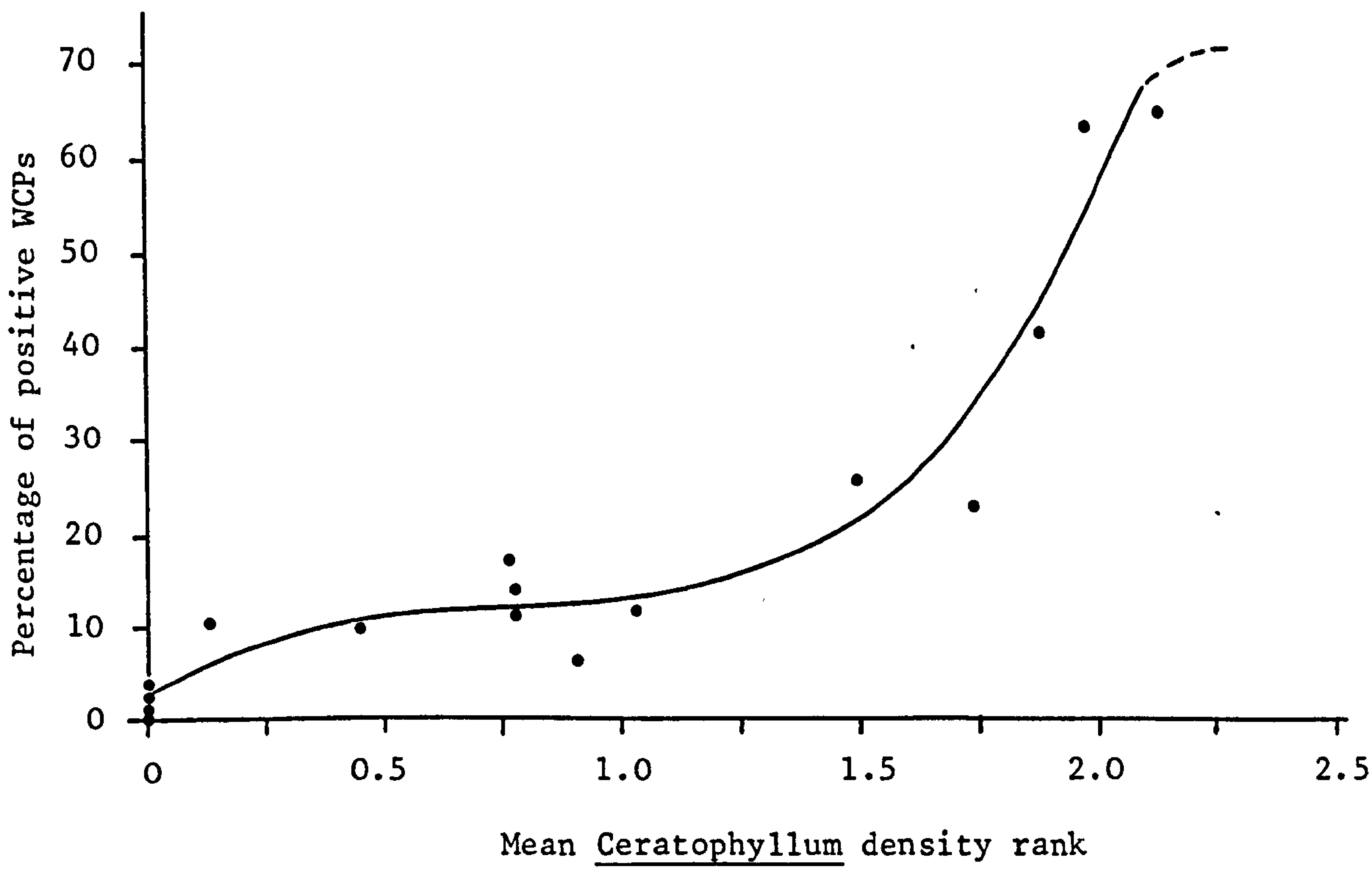


Fig. 7. Relationship between Ceratophyllum density and cercarial-infested water contact points (from Klumpp and Chu, 1980).

II. PRESENT RESEARCH

CHAPTER 5

ORGANIZATION OF SURVEYS AROUND THE LAKE, AND SNAIL SAMPLING TECHNIQUE

5.1 INTRODUCTION

Since one main purpose of the present research was to obtain information on the ecology of S. haematobium transmission around the Volta Lake through monthly sampling of B. rohlfsi, it is important to describe in detail the organization of the surveys, degree of coverage in the sampled villages, and the snail sampling technique employed.

5.2 MATERIALS AND METHODS

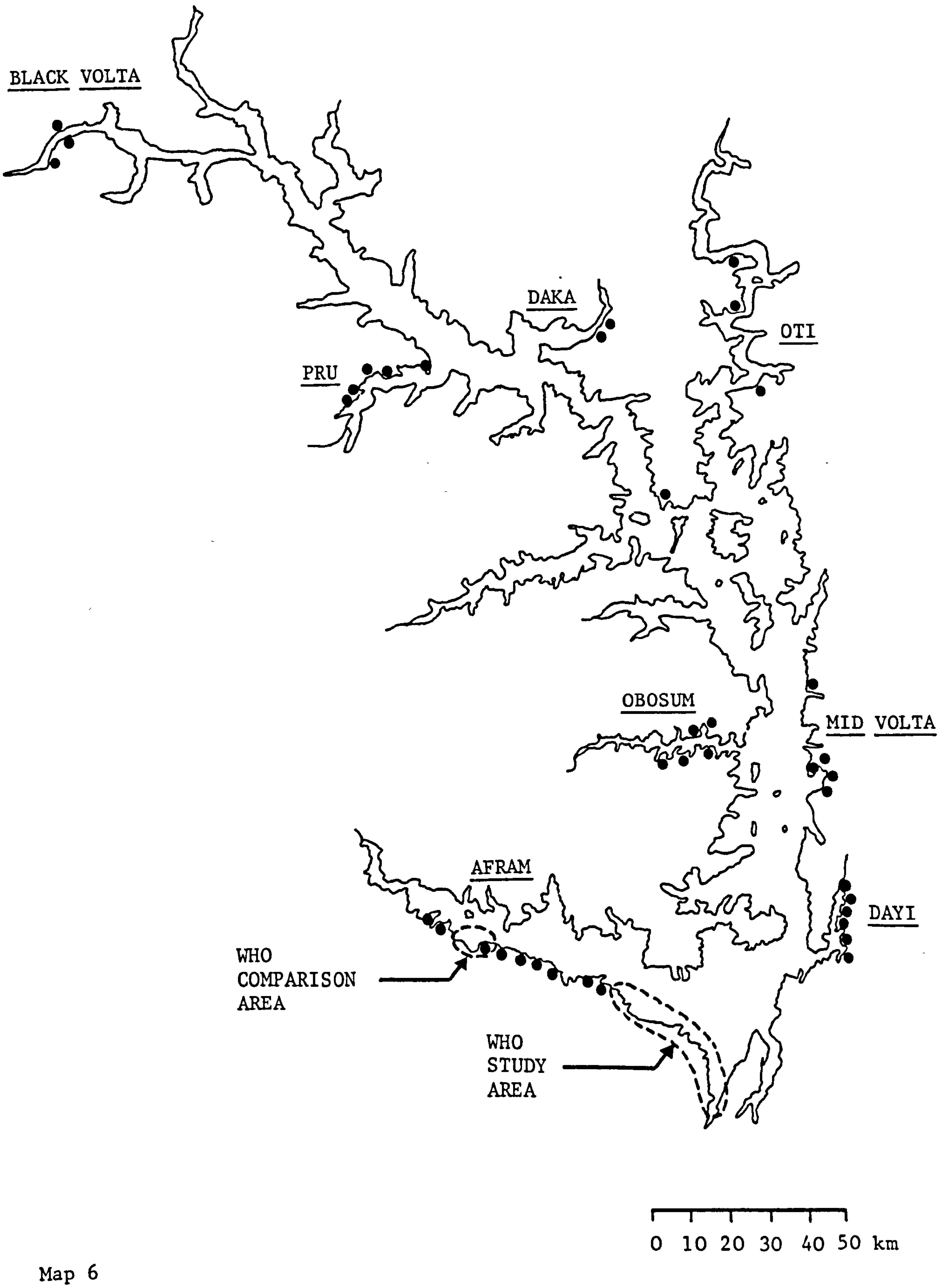
5.2.1 Villages selected

Fifty-seven WCPs in 39 lakeside villages were selected for the monthly sampling. Nine villages were in the large Afram branch, 6 in the Dayi branch, 5 each in the Obosum, Mid Volta, and Pru branches, 4 in the Oti branch, 3 in the Black Volta branch, and 2 in the small Daka branch (Map 6). Twenty-two villages were on the western side of the lake and 17 were on the eastern side. Fourteen villages were in the northern half and 25 were in the more densely populated and accessible southern half. (Each village is described in detail in chapter 7.)

5.2.2 Composition of team and vehicles used

For the entire 20 months of field work, the author employed 3 Ghanaian assistants. They were mainly needed to compose a consistent, 4-man snail sampling team so that results would be comparable to those from man-time sampling in the WHO project. But the assistants were also essential for logistical support, and for translating Ghanaian languages.

Two cars were used in the surveys. One was a reinforced Peugeot 404 van (on loan from the Ghana Ministry of Health) and the other was a 1200 cc Volkswagon "Beetle". For lake travel, a 5 metre, traditional fishing canoe was used, powered by a single 15 HP, Evinrude outboard engine.



Map 6

Location of the 39 study villages (●) in the different lake sections and in relation to the WHO study and comparison areas.

5.2.3 Monthly sampling programme

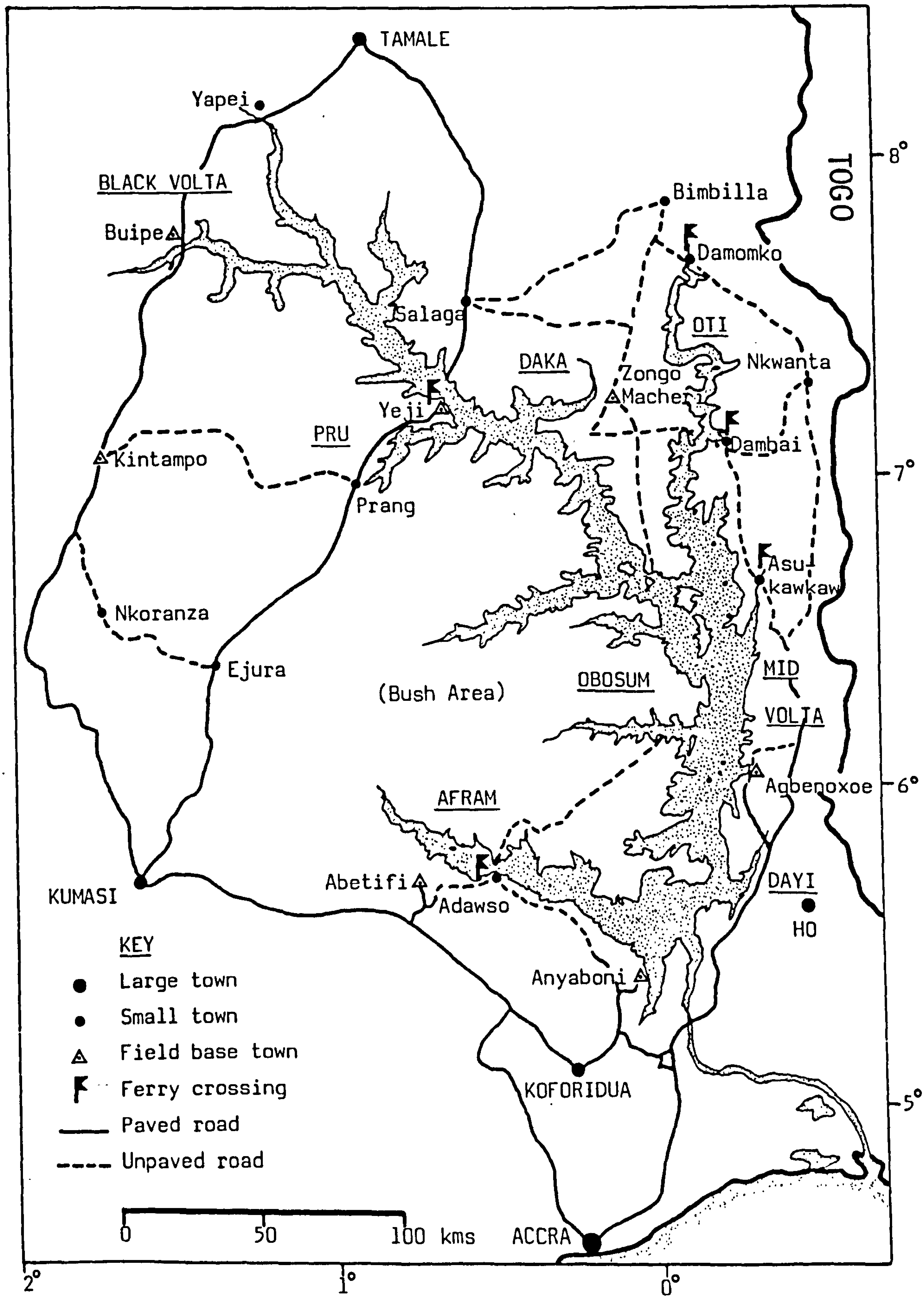
The monthly programme can be easily understood by following the description below with Map 7.

From approximately the 3rd to the 14th day of each month, the team stayed at Agbenoxoe where malacological, epidemiological, and sociological studies were being conducted. Sampling in the other villages of the Mid Volta and Dayi branches of the lake were carried out in this period, all villages being within a 1-hour car drive, or short canoe trip from Agbenoxoe.

From June 1979 onwards, the 5 villages at the Obosum branch were reached by motorized canoe from Agbenoxoe. In calm conditions, the journey took 3 hours to Bridgeanu-Ahenkro, the nearest of the sampled Obosum villages. To complete snail sampling (and periodic epidemiological work), it was necessary to camp for 1 - 2 nights on the shore of the Obosum branch before returning by canoe to Agbenoxoe.

Villages in the 4 northern branches were usually sampled between the 16th and 24th day of each month. Because of bad roads, non-functioning ferry boats, and other unforseen logistical problems, there was no consistent way to reach the northern villages. The preferred way was to drive from Agbenoxoe to Zongo-Macheri along the northeastern roads, and after sampling in the Daka and Oti villages from that temporary field base, to continue by road to the Pru and Black Volta villages via Yeji or Tamale. But if the Dambai and Damonko ferries were not operating (a regular occurrence in 1980), it was necessary to drive from Agbenoxoe to Yeji (Pru branch) via Accra and Kumasi, a 2 day trip. After sampling in the Pru villages (1 - 2 days of work), a further attempt was made to reach the Daka and Oti villages from Yeji. But if the Yeji ferry was not running, work in the latter sections was cancelled for the month, and the team then proceeded by road to Kintampo or Buipe for one day of sampling in the 3 Black Volta villages.

Upon returning from the north, sampling was normally conducted at the 9 Afram villages during the 4th week of the month. The main field base for this area was at Abetifi. Before June 1979, the team sampled in the 5 Obosum villages during the same week, usually crossing the lake with the Peugeot van on the ferry from Kwahu Adawso, and then



Map 7

Roads, ferry crossings, and field bases used in surveys.

driving to Bridgeanu-Ahenkro. The remaining 4 Obosum villages were reached by paddling to them in borrowed fishing canoes.

The minimum distance travelled around the lake each month to reach the 39 villages was approximately 2,130 km - 2,000 km by road and 130 km by canoe.

5.2.4 Degree of coverage in the 39 villages

The monthly programme was very demanding and it was impossible to obtain the full quota of samples in all 39 villages every month. Table 13 lists months in which sampling could not be carried out in some of the villages and gives reasons why this happened. Coverage was excellent in the southern sections of the lake sampled. Although many factors limited sampling in the northern branches, Black Volta and Pru villages were reached 80% of the time, and Oti and Daka villages (except Dambai) were reached 65% of the time.

5.2.5 Snail sampling technique

The chosen snail sampling technique was essentially the same as the modified man-time method used in the WHO project. There were only 2 modifications in the present study which made collecting more efficient. One was that the full 4-man team did not always sample together in a WCP if the WCP was small and confined. Then, 2 men searched together for 30 minutes - the same effort as 4 men searching for 15 minutes but with less habitat disturbance. The second modification was that at open beach WCPs, all sampling was done within 3 - 5 m from shore, and covered the full presumed width of the WCP plus a few metres to each side. In the WHO project, sampling was more box-like, with 2 men sampling near shore in the central part of the WCP and 2 men sampling about 5 - 10 m from shore behind them.

The following plates show how the team was basically positioned to collect snails during the 3 "lake seasons" when WCPs were very different in size and shape. It was learned from the WHO project that in pocket and channel-shaped WCPs, most snails and infected specimens were close to shore but on the sides of the WCPs along the emergent vegetation boundary. In open beach WCPs (during lake regression) almost all infected snails were within 5 m from shore.

Table 13. Months in which study villages were not sampled and reasons why.

BRANCH	1978		1979												1980					
Village	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
AFRAM																				
Nahrpawnya									a	a	a									
Sonukpo									a	a	a									
Dortopong									a	a	a									
Kpetinu																				
Asuboni																				
K. Adawso	b																			
Bekoe B																				
Asumjeri																				
Dedekrom																				
DAYI																				
Sodzi Kope																				
Kpeve Tornu																				
Woadzi Tornu																				
Kpo Kope																				
Quarters																				
Vakpo Aneta																				
OBOSUM																				
B.-Ahenkro																				
Ntonaboma	b									c										
America Kope										c										
Konkra										c										
Sodzi Kope										c										
MID VOLTA																				
Agbenoxoe																				
Amedzake K.																				
Kpandu Dafor																		d	d	d
Dafor Tornu																				
Domiabra																				
PRU																				
Kajai						e		f		g		g								
Tornu No. 1						e		f		g		g								
Prambo						e		f		g		g						d	d	d
Domiabra						e		f		g		g								
Kofi Bassari																				
BLACK VOLTA																				
Abogysekrom						e		f		g		g								
Ben Krom						e		f		g		g								
Buipe						e		f		g		g								
OTI																				
Bladjei			h			e		f		a		a		j					i	
Kitari			h			e		f		a		a		j					i	
Dambai			h			e		f		a		a		j		h	h		i	h
K.-Krachie T.			h			e		f		a		a		j					i	
DAKA																				
Burae			h			e		f		a		a		j					i	
Dendor			h			e		f		a		a		j					i	

a = roads washed out; b = village not yet selected; c = storms on lake; d = WCP no longer used; e = lack of time; f = revolution in Ghana; g = shortage of petrol; h = ferries broken down; i = team member injured; j = Christmas.

Plate 21. Sampling positions in pocket-shaped WCP

Plate 22. Sampling positions in open-beach WCP. Photograph was taken during preliminary work before 4-man team was assembled.

Plate 23. Sampling positions in small channel-shaped WCP. In such small WCPs, 2 men searched on each side for 30 minutes.


1
2
3
4


1
2
3
4


1
2

The procedure for measuring, crushing, and examining B. rohlfsi was the same as in the WHO project, but without counts made of cercariae (Klumpp and Chu, 1977).

5.2.6 Recording of vegetation in WCPs

As in the WHO project, a sketch map was made of every WCP sampled, which included the estimated dimensions of the WCP and the main species of plants growing in and around it (recording form shown in Appendix A). An innovation in the present study was that the "density rank" of emergent weeds and Ceratophyllum was specifically recorded on the sampling form at the time of sampling. (This was not done in the project, and density rank of Ceratophyllum had to be deduced from later inspection of the sketch maps.)

The amount of emergent, rooted weed growth was ranked as follows: 0 = no weeds or a few fragments; 1 (light growth) = a solid zone of weeds extending 1 - 5 m from shore into the water on one or both sides of the WCP, or, if there was no side growth, scattered over 15 - 25% of the WCP; 2 (medium growth) = a solid zone of weeds extending 5 - 10 m from shore into the water on both sides of the WCP, or, scattered over 25 - 50% of the WCP; 3 (heavy growth) = a solid zone of weeds extending 10 m or more from shore into the water on both sides of the WCP, or scattered over more than 50% of the WCP.

For Ceratophyllum density rank in WCPs, 0 = no Ceratophyllum or a few scattered fragments; 1 (light growth) = covering 5 - 15% of the bottom surface area; 2 (medium growth) = covering 15 - 50% of the bottom surface area; and 3 (heavy growth) = covering more than 50% of the bottom surface area.

5.2.7 Sensitivity of snail sampling

In the present study, one experiment was conducted to see what percentage of adult B. rohlfsi could be collected in 1 man-hour of sampling in relation to the total population of adult B. rohlfsi in the WCP.

Three different WCPs were selected, all with hard, sandy bottoms. WCP 1 was an open beach containing 2 circular patches of *Echinochloa*, each about 1 m in diameter and with *Ceratophyllum* covering about 50% of the bottom of the WCP. WCP 2 was pocket-shaped, similar in shape and size to that shown in Plate 21 but with patches of *Ceratophyllum* covering about 30% of the bottom surface area. WCP 3 was another pocket-shaped WCP, but about to turn into an open beach. Two side walls of *Echinochloa* extended 9 m from shore into the water and *Ceratophyllum* fragments covered about 10% of the bottom.

In each WCP, all sampling was conducted in areas shown in Table 14, and took place between 07 - 09 h. *B. rohlfsi* specimens about 2.5 mm or greater in shell height were collected. On the first day at each WCP, sampling was done in the normal way - 4 men searching together for 15 minutes (1 man-hour). Snails were picked from rooted vegetation by hand, using long forceps, and from *Ceratophyllum* that was scooped-up by sieves (as in Plate 22). The sieves were also used to scrape the total bottom area of each WCP where no vegetation existed. Because of habitat disturbance during sampling, each WCP was left to settle after the first man-hour of searching until the following morning. People cooperated by not using the WCPs during the 2-day sampling periods. Because there was no offshore vegetation or winds (or fishermen) bringing in new vegetation, there should have been little if any invasion by "allochthonous" *B. rohlfsi* overnight.

On the second day, each man searched in the same manner as before, but for 45 minutes (3 man-hours). To prevent repetitive searching of examined vegetation and debris, all loose bits were thrown from the WCP after being examined for snails. By the end of the 3 man-hours, almost all macrophytes, sticks, and logs had been thoroughly examined, and the sandy bottoms of the WCPs thoroughly scraped with the sieves. Results of the sampling are presented in Table 14.

Although some adult snails were undoubtedly missed during the searches, the experiment did show that a high proportion of adult *B. rohlfsi* were collected in the first man-hour of sampling in relation to what could be found after a subsequent, exhaustive search, and therefore in relation to the approximate total adult population of *B. rohlfsi* which existed in the sampled areas.

Table 14. Details of snail sampling experiment.

WCP	Area sampled: Shore-line width (m)	Dist. from shore (m)	Max. depth (m)	No. of adult *B. rohlfsi*: Day 1, 1 man-h searching	Day 2, 3 man-h searching	% of total found during first man-h of searching
1) Open beach	30	5	0.6	103	58	64.0
2) Pocket	15	7	1.0	81	61	56.7
3) Pocket	20	9	0.6	4	3	57.1

CHAPTER 6

GENERAL FINDINGS ON THE ECOLOGY OF *B. ROHLFSI* IN THE LAKE AND VARIATION AND CONSISTENCY OF CERCARIAL TRANSMISSION POTENTIAL

6.1 INTRODUCTION

This chapter presents analysis of overall sampling results for B. rohlfsi around the lake, from November 1978 to June 1980. The results include (1) the frequency distribution of B. rohlfsi in WCPs, (2) infection rates by S. haematobium, (3) seasonal variation in number of total and infected B. rohlfsi, (4) monthly and seasonal indices of cercarial transmission potential, (5) physical factors affecting the distribution, density, and infection of B. rohlfsi in WCPs, (6) analysis of the snail's intrinsic rate of natural increase, (7) size and age-specific infection rates, and (8) a proposed mathematical model to quantify the rates at which B. rohlfsi were gaining and losing S. haematobium infections in the Volta Lake.

6.2 FREQUENCY DISTRIBUTION

The overall frequency distribution of the number of B. rohlfsi collected in WCPs is shown in Figure 8. The mean number of snails per WCP from all 984 samples was 10.3 (±23.5), but 592 samples yielded no snails. The observed distribution approximated the negative binomial but was significantly different from the expected curve ($\chi^2 = 70.48$, $P < 0.001$).

By comparison, the total mean, precontrol number of B. rohlfsi collected per WCP in the WHO project was 10.1 by palm-mat sampling (2 largest WCPs sampled per village) and 6.7 by man-time sampling.

Figure 8 also shows that snail infection rates were high for each class grouping. There was no consistent linear correlation between numbers of snails collected per sample and rates of S. haematobium infection. The 2 parameters were positively correlated from the class of 1 - 9 snails per sample to the class of 50 - 59 snails per sample ($r = .93$, $P < 0.01$). But with greater snail density, snail infection rates decreased ($r = -.73$, $P > 0.05$).

Snail infection rates were high even when less than 10 B. rohlfsi were collected per sample (Table 15). For this group, the highest infection rate - 16.0% - occurred when only 1 snail was found in a WCP.

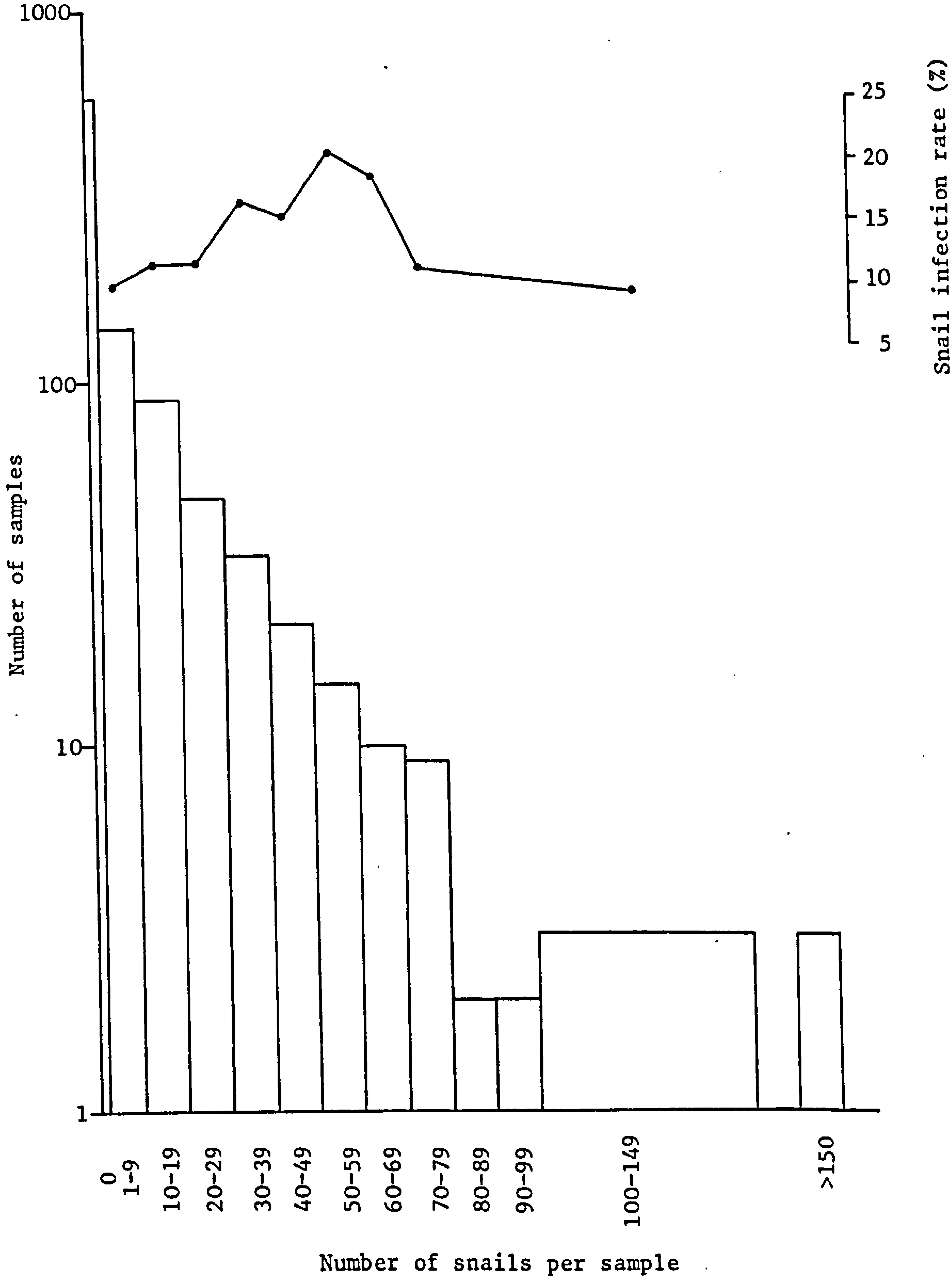


Fig. 8. Frequency distribution of number of snails collected per sample, and percentage of snails infected with patent S. haematobium cercariae in each major class grouping.

Table 15. Snail infection rate per class of low snail density.

Number of snails per sample	1	2	3	4	5	6	7	8	9
No. of samples	25	24	19	15	15	16	9	11	11
No. of + snails	4	4	7	2	7	5	9	11	14
Infection rate	16.0	8.3	12.3	3.3	9.3	5.2	14.3	12.5	14.2

6.3 OVERALL SNAIL INFECTION RATES

Out of 10,030 total *B. rohlfsi* collected over 20 months, 1199 (11.95%) contained at least some mature, active *S. haematobium* cercariae. An additional 271 snails contained only immature cercariae. The total percentage of *B. rohlfsi* with readily detectible *S. haematobium* cercariae was therefore 14.65%. Considering that early daughter sporocyst and all mother sporocyst stages could not be detected when the snails were crushed, the actual percentage of *B. rohlfsi* which were infected with the trematode was probably over 20%.

There was no confusion with cercariae other than *S. haematobium*. Only 30 snails (0.3%) were infected with other brevifurcate cercariae (mainly strigeid types), and only 261 specimens (2.6%) were infected with xiphidiocercariae.

In the WHO project, 1.5% of total snails contained xiphidiocercariae, and less than 0.3% contained other, non-schistosome cercariae.

Table 16 lists snail infection rates from other major field studies in different parts of the world. The overall infection rate from the Volta Lake was higher than in any of the other surveys. This was probably due to 3 inter-related reasons: (1) High focality of transmission in the Volta Lake; (2) high prevalence rates in humans; and (3) high susceptibility of *B. rohlfsi* to infection with the "rohlfsi" strain of miracidia.

Country	Habitats	Schistosome species	Snail	Overall snail infection rate (%)	Reference
Egypt	Irrigation canals	*S. haematobium*	*B. truncatus*	0.09 - 0.76	El-Gindy & Rushdi, 1962
Egypt	Streams, canals	*S. haematobium*	*B. truncatus*	0.4	Chu et al., 1972
Tanzania	Ponds	*S. haematobium*	*B. (P.) n. productus*	4.7	Webbe, 1962
Tanzania	Reservoirs	*S. haematobium*	*B. (P.) n. productus*	0.9	Kinoti, 1964
Tanzania	Natural lake	*S. mansoni*	*B. choanomphala*	0.2 - 3.3	Magendantz, 1972
Kenya	Streams	*S. mansoni*	*B. pfeifferi*	1.6	Teesdale, 1962
Madagascar	Irrigation canals, ponds, swamps	*S. haematobium*	*B. liratus*	0.3	Degremont et al., 1972
Iran	Irrigation canals, ponds, swamps	*S. haematobium* + *S. bovis*	*B. truncatus*	0.4 - 1.6	Chu et al., 1968
St. Lucia	Streams, ponds, marshes, banana drains	*S. mansoni*	*B. glabrata*	0.5	Sturrock, 1973
	Rice fields, streams	*S. japonicum*	*O. quadrasi*	4.7	Pesigan et al., 1958

Table 16. Snail infection rates from various field studies.

6.4 SEASONALITY OF TRANSMISSION

6.4.1 Lake seasons

Before a description is given of the monthly variation in numbers of total and infected snails collected, it is necessary to look at the influence of the 3 lake seasons of each lake cycle. These seasons, reviewed in chapter 4, were described as the rising water, early to mid-drawdown, and late drawdown phases. However, in the present study, it was learned that a better description and division of the lake cycle (in terms of the ecology of *S. haematobium* transmission) would be as follows: (1) flood season = August to November (instead of August to October); (2) early to mid-drawdown season = December to March (instead of November to March); and (3) low water season = April to July (same). Figure 9 shows the inter-relationship between the 3 lake seasons, lake level fluctuation, and the percentage of WCPs which contained rooted plants.

6.4.2 Monthly number of snails

Figure 10 gives numbers of total and infected *B. rohlfsi* collected each month. Despite failure to reach all WCPs each month, seasonal trends are clear. During the first 8 months, the number of total snails collected was influenced by the low lake level. In the 4 months' flood season of 1978, the lake rose only 2.1 m and was at its lowest ever November peak. Zones of inundated emergent weeds were therefore shorter than in normal years. But the low lake rise prevented a flushing effect, and a relatively large number of snails was found in November 1978. Because of the short zones of emergent plants in and around WCPs, numbers of total snails did not build-up to high levels in the following months of December to March. During April and May 1979, *Ceratophyllum* growth was heavy in the Afram and Obosum branches, and this prevented a rapid drop-off of total snail numbers, as would be expected after WCPs had become transformed into open beaches.

From late July until November 1979, the lake rose 5.2 m - its greatest ever seasonal rise. This was catastrophic for *B. rohlfsi*, and few snails were collected until December 1979. But the large lake rise caused long zones of emergent weeds to appear in the littoral zone,

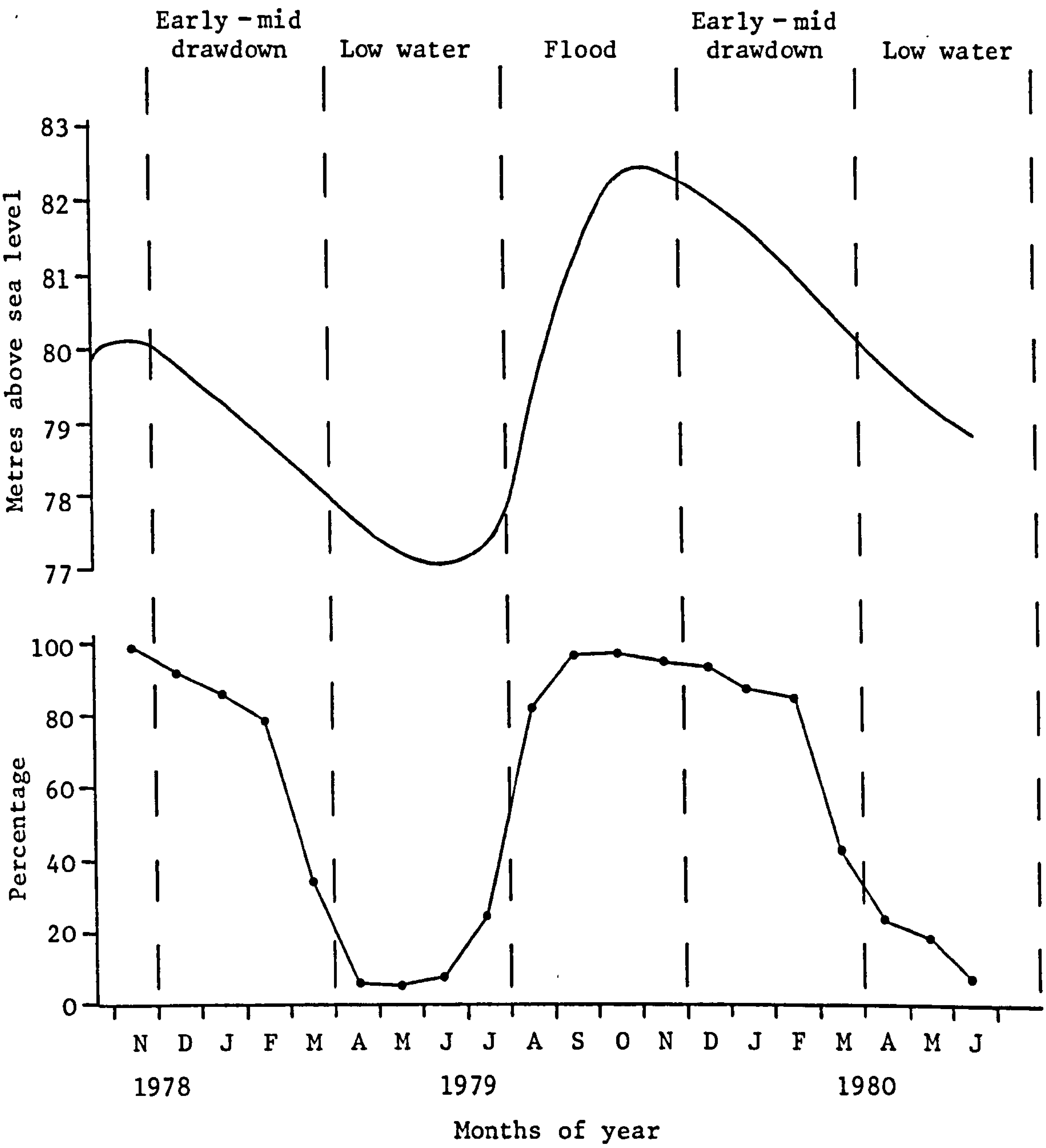


Fig. 9. Lake seasons according to surface elevation of the lake, and percentages of water contact points containing rooted, emergent plants.

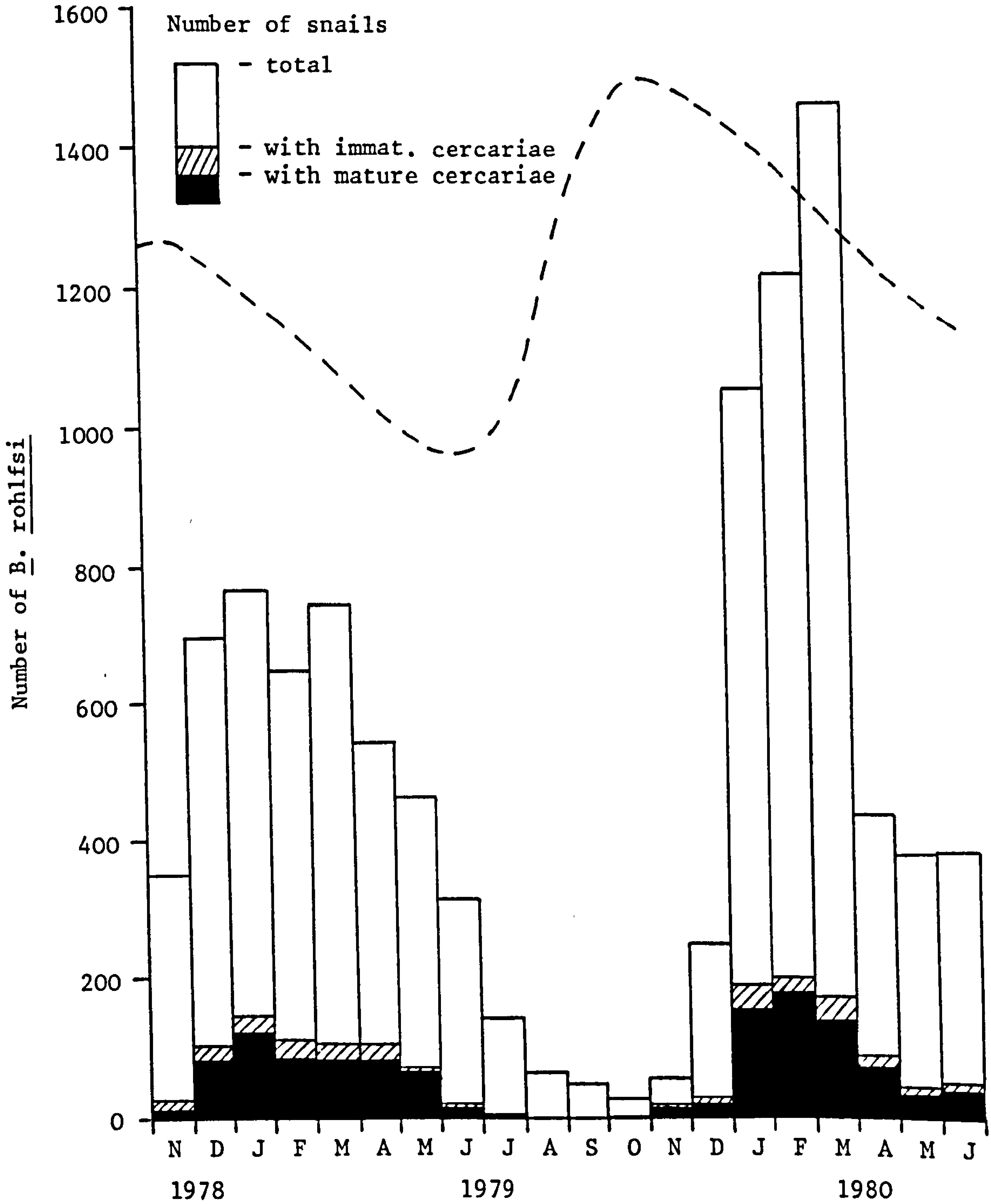


Fig. 10. Monthly number of B. rohlfsi collected, and relative surface elevation of lake.

and this promoted large snail populations during January, February, and March 1980. By April, most WCPs had receeded beyond the emergent weed zone, and from April to June, fewer snails were found in the open-beach WCPs.

In each year of sampling, the greatest number of infected snails were collected within the early to mid-drawdown season of December to March, with an earlier build-up during the first year because of less flooding. No infected snail was found during August and September 1979 when the lake was rising most rapidly.

The observed pattern of seasonal variation in total and infected *B. rohlfsi* was similar to what was recorded in the WHO project (cf. Fig. 5). One can conclude, therefore, that despite differences in plant succession, sampling location, and absolute level of the lake, the basic seasonality of cercarial transmission in the Volta Lake has remained stable.

6.4.3 Indices of transmission potential

Chu and Dawood (1970) developed the concept of monthly "cercarial transmission potentials" while studying transmission of *S. mansoni* by *B. alexandrina* in the Nile delta. Although not stated explicitly, each monthly "potential" was part of a relative index for the year. Chu and Dawood quantified these potentials from 3 different parameters based on monthly snail sampling results: (1) snail infection rates, (2) numbers of infected snails, and (3) numbers of presumed *S. mansoni* cercariae shed from the infected snails over 24 hours, beginning just after collection. Chu and Dawood found that monthly transmission potentials based on numbers of infected snails or numbers of cercariae shed were most accurate for assessing the relative monthly "danger" for human infection; transmission potentials from snail infection rates were least reliable, because the rates were often independent of snail density.

Similarly, snail infection rates could not be used to assess the seasonality of *S. haematobium* transmission in the Volta Lake. It was already shown that infection rates were not always dependent on density of total *B. rohlfsi* in WCPs.

In the following section, analysis will focus on quantifying indices of transmission potential for each month of the year, and will be based on the following parameters from total snail sampling results around the lake: (1) the percentage of cercarial-infested WCPs, (2) the number of infected snails, and (3) the most probable number of S. haematobium cercariae in the infected snails at the time of their collection.

Percentages of cercarial-infested WCPs

Figure 11 shows the percentage of WCPs sampled each month which contained at least one B. rohlfsi with patent S. haematobium cercariae.

This method of analysing the potential for transmission each month is best for appreciating the spread of transmission around the lake, because it is not biased by extreme values. For example, in April 1979, 83 infected snails were collected from 37 WCPs in 26 sampled villages. But 60 of these came from one WCP - at Bridgeanu-Ahenkro in the Obosum branch.

The percentage of cercarial-infested WCPs gave similar curves of build-up and decline of transmission potential during the first and second years of sampling, despite a difference of over 3 m in absolute lake level. Each November, only 7 - 10% of the WCPs were "positive". By each December, this rose to 23 - 31%. The widest spread of transmission was each January when between 40 - 47% of the WCPs contained infected snails. Then, each year from February to June (except April 1980), the percentages dropped-off steadily. Only 2.7% of the WCPs were positive in the flood period of August to November.

When the monthly proportions of cercarial-infested WCPs were calculated for each of the 12 months of the year, a relative index of transmission potential could be constructed (Table 17a).

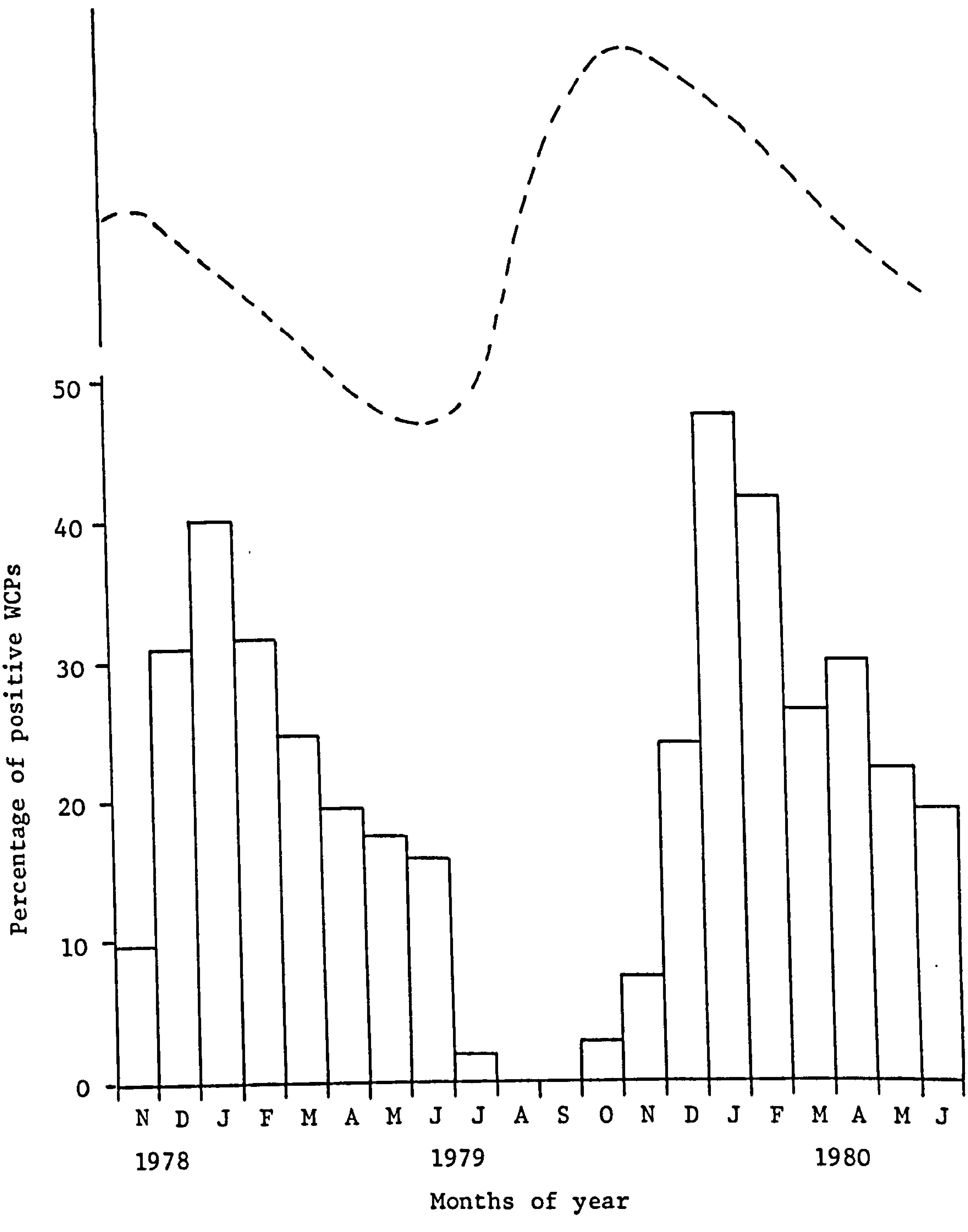


Fig. 11. Monthly percentages of cercarial-infested water contact points, and relative surface elevation of lake.

Table 17a. Relative monthly index of transmission potential (ITP) by percentage of cercarial-infested WCPs.

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
No. + WCPs	29	46	40	28	22	20	16	1	0	0	1	9
No. WCPs sampled	104	105	110	110	86	102	90	52	27	52	37	109
Proportion + (1)	.28	.44	.36	.27	.26	.20	.18	.02	0	0	.03	.08
Rel. ITP, %*	13	21	17	13	13	9	8	1	0	0	1	4

* Calculated as follows: each value of (1) divided by $\Sigma(1)$ times 100.

By this method of analysis, the most important months for transmission in decreasing order were: January, February, December, March, April, May, June, November, July & October, and August & September.

By season, 64% of the yearly transmission potential was in the early to mid-drawdown season of December to March, 31% was in the open beach (low water) season of April to July, and 5% was in the flood season of August to November.

The 3 respective periods can therefore be classified as the high, sporadic, and low transmission seasons.

Comparison of results with those from WHO project

Figure 12 compares the results in Table 17a with monthly, precontrol percentages of cercarial-infested WCPs recorded in the WHO project.[1] The curves show close agreement for the months of November to June and for September and October. The discrepancy in results for July and August can be explained as follows. The lake level rose only 0.6 m and 0.8 m in July - August, 1973 and 1974 respectively. These small rises kept WCPs fairly stationary; hence, B. rohlfsi were not destroyed by flooding, and specimens had sufficient time to come into contact with S. haematobium miracidia and later, to shed cercariae. By contrast, the lake rose almost 2 m in July - August, 1979.

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1 To get the most valid comparison, results from the WHO project combined baseline data from the 2 main WCPs of the 8 villages sampled with palm-mats and the 8 villages sampled by the man-time method. Results for WCP positivity were almost equal in each lake season in the 2 groups of villages. There were slightly more total snails per sample and infected snails per sample in the WCPs sampled by palm-mats. But there was no way statistically to judge which sampling method was more efficient because the 2 sets of villages were different in ecology.

Parameter	Sampling method	Dec-Mar	Apr-Jul	Aug-Nov	Total
Percentage of cercarial-infested WCPs	Palm-mats	33.3	18.4	9.4	20.8
	Man-time	29.5	17.9	8.3	20.6
No. of total snails per sample	Palm-mats	15.7	5.9	6.6	8.9
	Man-time	12.6	4.1	3.2	7.0
No. of infected snails per sample	Palm-mats	1.60	0.28	0.44	0.70
	Man-time	1.40	0.24	0.14	0.64

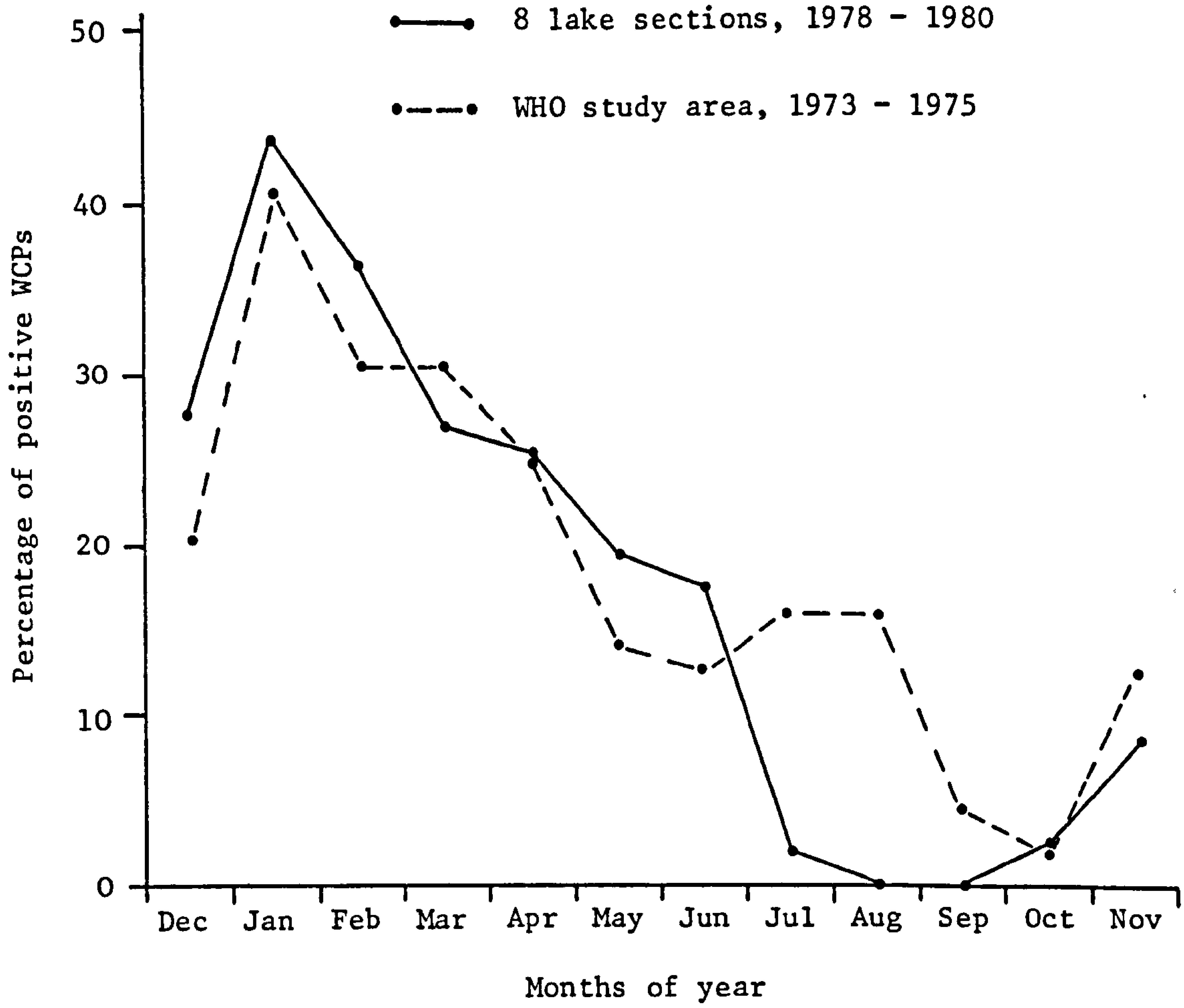


Fig. 12. Comparative percentages of cercarial-infested water contact points for each month of the year.

Mean number of infected snails per WCP

Mean values for all 20 months are shown in Figure 13. Except for April 1979 when the result was made artificially high by limited coverage and the large number of infected snails at Bridgeanu-Ahenkro, the values show the same seasonal picture of transmission build-up and decline as the raw numbers in Figure 10.

By mean number of infected snails per WCP, monthly transmission potentials are given in Table 17b. The results indicate that 68% of the yearly transmission potential was between December and March, 29% was between April and July, and only 3% occurred between August and November.

Table 17b. Relative monthly index of transmission potential (ITP) based on mean number of infected snails per WCP.

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
No. + snails	104	276	261	219	152	98	55	5	0	0	1	28
No. WCPs sampled	104	105	110	110	86	102	90	52	27	52	37	109
Mean No. + snails/ WCP (1)	1.0	2.6	2.4	2.0	1.8	1.0	0.6	0.1	0	0	.03	0.3
Relative ITP,%*	9	22	20	17	15	8	5	1	0	0	<1	2

* Calculated as follows: each value of (1) divided by $\Sigma(1)$ times 100.

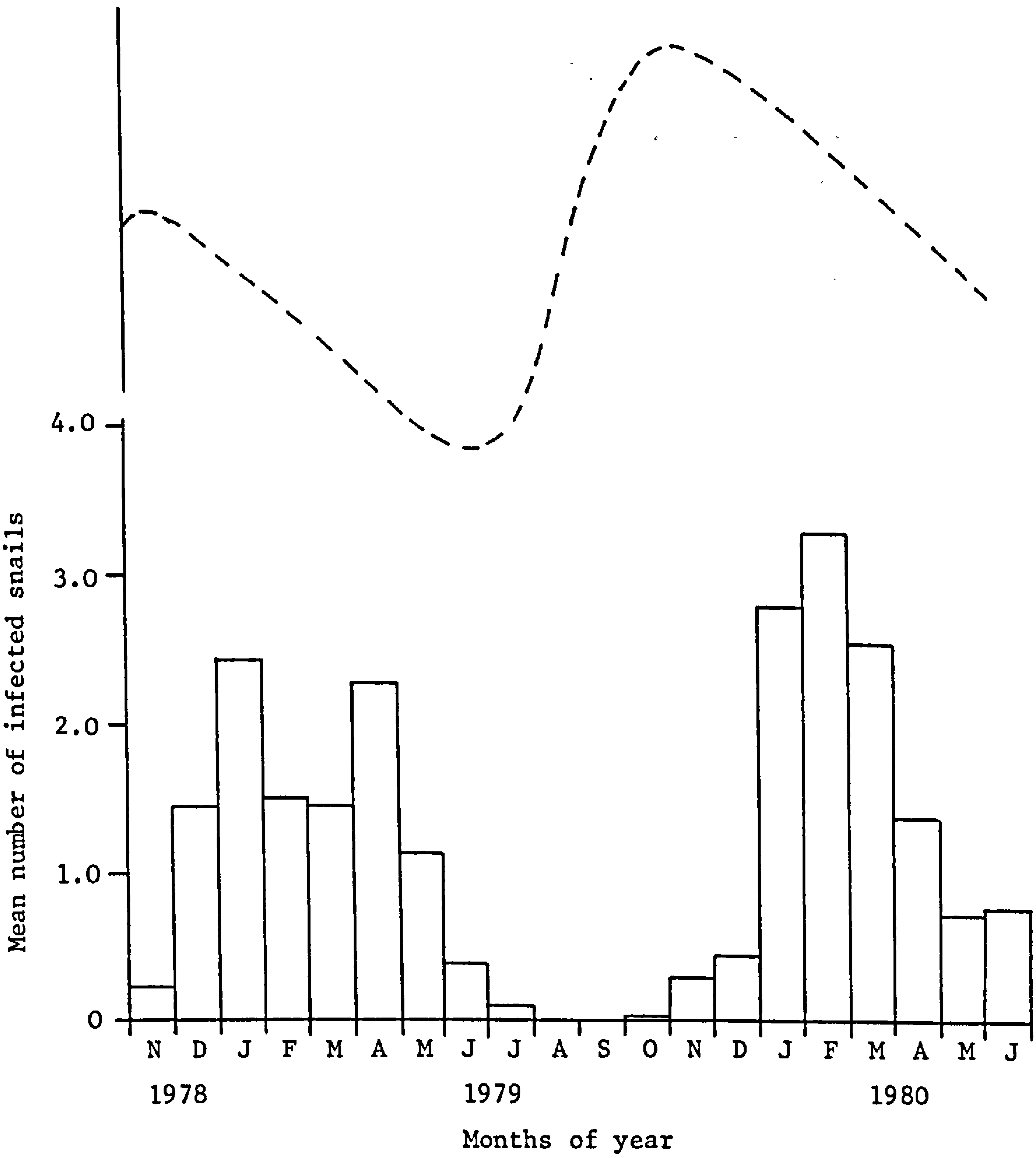


Fig. 13. Mean number of infected B. rohlfsi per sampled water contact point, and relative surface elevation of lake.

The mean number of infected snails per sample for each month of the year is compared with the same parameter from total precontrol sampling results in the WHO project (Figure 14).

As would be expected from differences in sampling location, sampling method, and time, the 2 sets of results were quantitatively different - the overall mean number of infected snails detected per sample in the lake between 1978 and 1980 was 1.8 times higher than it was in the WHO study area between 1973 and 1975. However, except for July and August, the 2 curves agreed qualitatively on the seasonal build-up, peak, and decline of transmission potential.

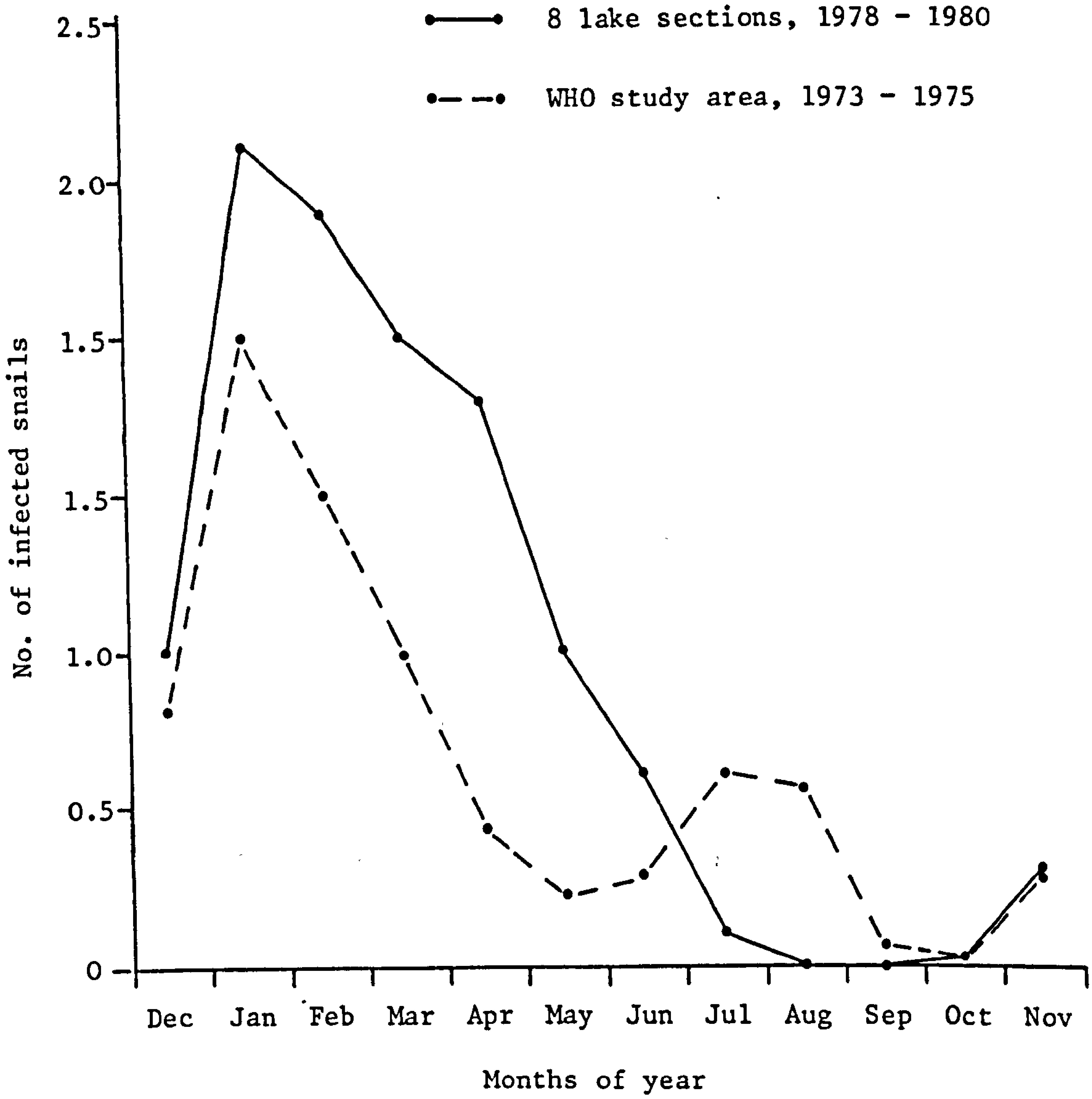


Fig. 14. Comparison of mean numbers of infected B. rohlfsi collected per sample for each month of the year.

Estimate of number of patent *S. haematobium* cercariae in infected *B. rohlfsi*

While the parameter of mean number of infected snails per WCP was a logical way to determine monthly transmission potential, a further refinement of it would be desirable, to take into consideration the variation in monthly mean size of the infected snails. It can be seen in Table 18 that there was variation in mean shell heights of infected *B. rohlfsi* by month and season. The differences in mean size between the December - March and April - July seasons was significant at the 99% level.

Table 18. Mean shell height (mm) of *B. rohlfsi* infected with patent *S. haematobium* cercariae.

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	A	S	Oct	Nov
5.91	5.93	5.91	5.63	4.69	4.76	5.16	6.6[a]	-	-	8.5[b]	6.75
	5.84, ±1.32				4.87, ±1.11						

[a] 5 infected snails; [b] 1 infected snail.

In Figure 15, the mean shell height of total *B. rohlfsi* collected each month is shown with its standard deviation, and the curve of relative lake level during the sampling period. Shell heights were largest during both early to mid-drawdown seasons, lower during both low water seasons, and lowest during the early part of the flood season. The rapid drop in mean shell height in April 1979 was caused by an unusually large number of small snails collected at Bridgeanu-Ahenkro. The temporary increase in shell height from April to July 1979 was due to snail populations maturing in *Ceratophyllum* in the Afram and Obosum branches.

The same seasonal pattern of variation in size of *B. rohlfsi* was noted in the WHO project (Klumpp and Chu, 1977).

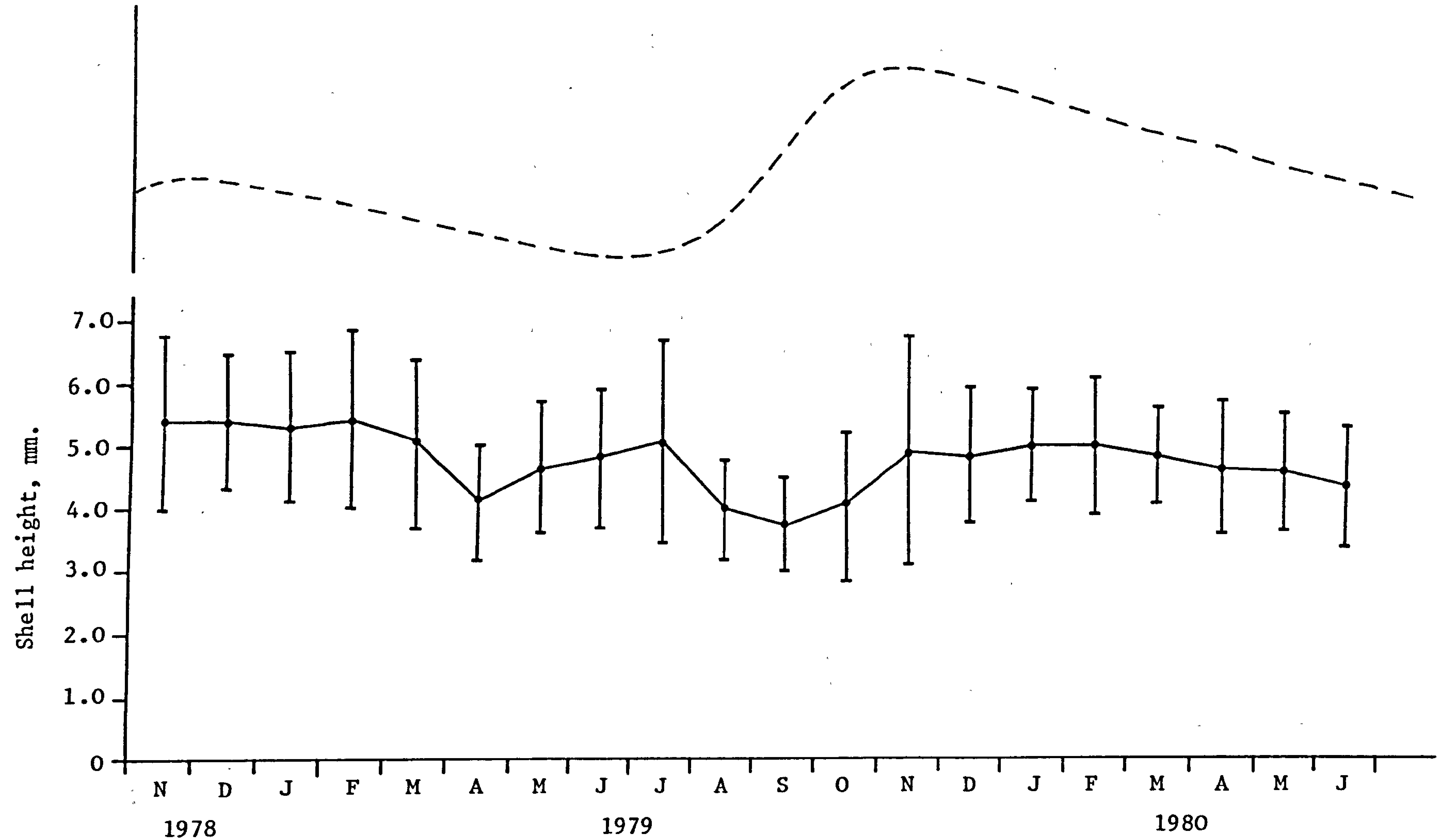


Fig. 15. Monthly mean shell height of total *B. rohlfsi* collected, standard deviations, and relative surface elevation of lake, 1978 - 1980.

Calculation of transmission potentials

Ideally, it would have been desirable to construct an index of transmission potential from the number of cercariae shed per day from collected,infected snails, as Chu and Dawood (1970) did in Egypt.

In the present study, lack of time and facilities prevented direct counting of presumed S. haematobium cercariae - either from shedding or from crushing.

However, it was possible to construct a monthly index of transmission potential from an estimation of the number of patent S. haematobium cercariae in the infected B. rohlfsi per WCP sampled (at the time of collection). This indirect calculation was as follows.

First, unpublished data (collected by the author in the WHO project) were available on counts of active,patent S. haematobium cercariae in 443 individually measured, and crushed B. rohlfsi. Snail-size measurements were to the nearest 0.5 mm of shell height.

Second, a scattergram was constructed by computer to show the relationship between individual cercarial counts and size of all 443 infected snails. The regression curve was fitted, and is shown along with the mean cercarial counts (for each class of shell height) in Figure 16. Standard deviations of the mean counts were illustrated to show that there was large variation in individual counts of cercariae per class of shell height. This was to be expected, since S. haematobium cercariae were in different stages of development at the time of examination. Some counts were made when cercariae were just maturing (e.g., only 1 or 2 active cercariae amidst many immature cercariae and "germ balls") while other counts were made at the peak of cercarial patency and density.

Third, because the regression curve corresponded closely to the mean number of cercariae per class of shell height, it was assumed that the curve would give a reliable estimate of the average number of patent S. haematobium cercariae per infected B. rohlfsi for any given shell height (when considering large numbers).

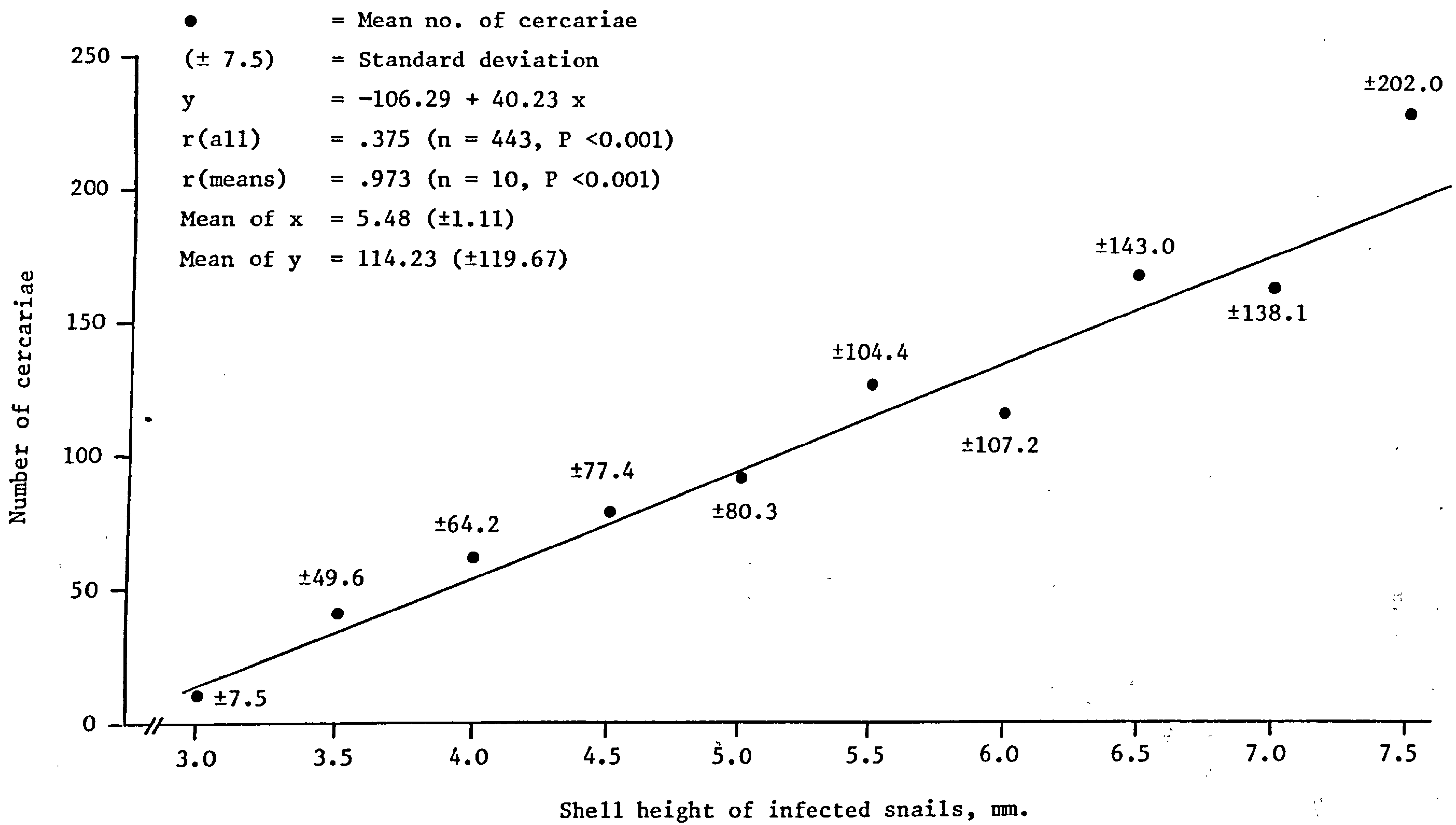


Fig. 16. Regression curve from scattergram of 443 infected B. rohlfsi (from WHO project, 1973 - 1975), by class of measured shell height, and showing mean number of patent S. haematobium counted in crushed snails.

Therefore, in Table 19, the mean shell height of all infected B. rohlfsi for each month of the year was applied to the regression line to give the estimated mean number of cercariae per appropriate shell height (line 2). These monthly estimates were then multiplied by the total number of infected snails actually collected for each appropriate month to give the total estimated monthly number of cercariae in all infected snails (line 4).

Finally, these monthly totals were divided by the number of WCPs sampled in the respective months. The quotients (line 6) were the monthly estimates of the number of patent S. haematobium cercariae in all infected snails collected per WCP at the time of sampling. Each relative monthly index of transmission potential was calculated from the latter quotients (line 7).

This indirect way of estimating numbers of cercariae is less desirable than actually counting cercariae shed from snails. Although the present method of quantifying transmission potentials is subject to more error than Chu and Dawood's (1970) method, confidence is gained by the large number of infected snails found in the present study (much more than in Egypt), and any error in the predicted number of cercariae would be constant for each month.

The influence of monthly variation in water temperature in the lake to affect snail growth and cercarial shedding capacity was not significant. Data on this are presented in section 6.6.

From Table 19, 73.4% of yearly transmission potential was expected between December and March, 22.9% was expected in April to July, and 3.7% was predicted for August to November.

Figure 17 compares results from Table 19 (line 6) with earlier precontrol results from the WHO project, calculated in the same way as in Table 19. In addition, another curve on monthly transmission potential in the WHO study area was included. This curve (dotted line) involved actual counts of S. haematobium cercariae in crushed snails, rather than estimates from the regression line. It can be seen that the 2 curves for the WHO study area (1973 - 1975) were in close agreement. Although both sets of the earlier data were quantitatively different from the present results, all 3 curves agreed qualitatively

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1. Mean shell height of + snails	5.91	5.93	5.91	5.63	4.69	4.76	5.16	6.60	-	-	8.50	6.75
2. Expected no. of cercariae for mean shell height of + snails	131	132	131	120	82	85	101	265	0	0	342	165
3. No. of + snails	104	276	261	219	152	98	55	5	0	0	1	28
4. Estimated no. of cercariae in all + snails	13624	34432	34191	26280	12462	8330	5555	1325	0	0	342	4620
5. No. of WCPs sampled	104	105	110	110	86	102	90	52	27	52	37	109
6. Estimated no. of cercariae in all + snails per WCP	131	328	311	239	145	82	62	25	0	0	9	42
7. Rel. ITP, % (6./Σ6. x 100)	9.5	23.9	22.6	17.4	10.6	6.0	4.5	1.8	0	0	0.6	3.1

Table 19. Relative monthly index of transmission potential (ITP) based on estimated number of patent cercariae in all infected snails (at time of collection) per number of water contact points sampled.

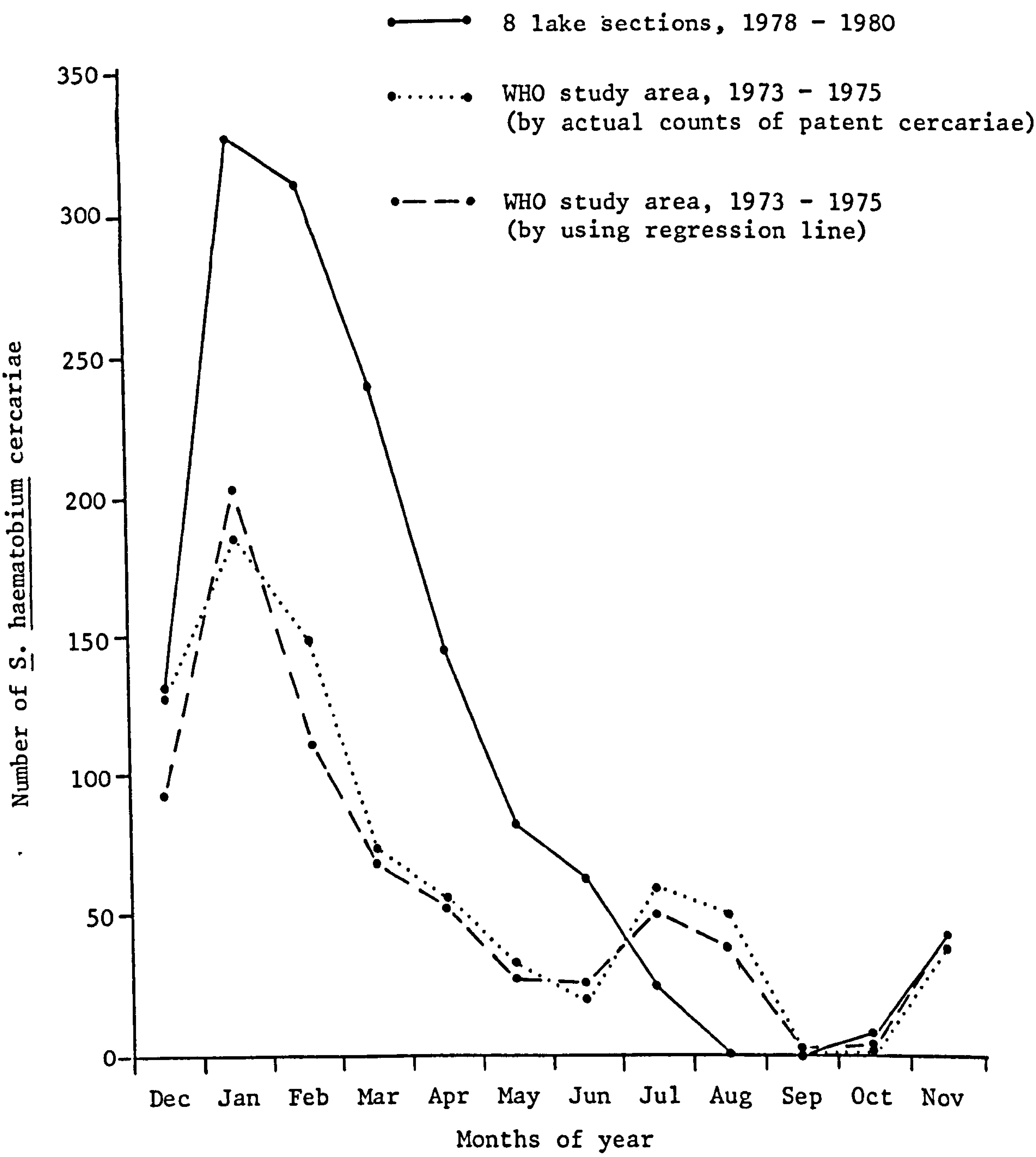


Fig. 17. Estimated number of patent S. haematobium cercariae in infected snails per WCP sampled (at time of collection).

in defining which seasons were most and least "dangerous" for *S. haematobium* transmission.

Comparison of monthly transmission potentials from all 3 methods of analysis

Figure 18 compares the monthly transmission potentials in the present study by the 3 different methods of analysis. All 3 showed good agreement, with most transmission expected between December and March (peaking in January), a steady drop from April to July, and low levels expected between August and November.

However, there were slight differences between the 3 methods. By the percentage of cercarial-infested WCPs, more transmission was expected in the open beach season than by the other 2 methods. By the mean number of infected snails per WCP, the December to March season was emphasized, at the expense of the open beach season. By the estimated number of cercariae in infected snails per WCP, the danger of transmission occurring between December to March was emphasized even further, due to larger snails in this season; conversely, lower transmission was expected between April and July, when infected snails were smaller.

All 3 methods have merit and all should be considered in field studies of this nature. During the present study, the true potential for transmission each month was probably within the range of the 3 sets of values.

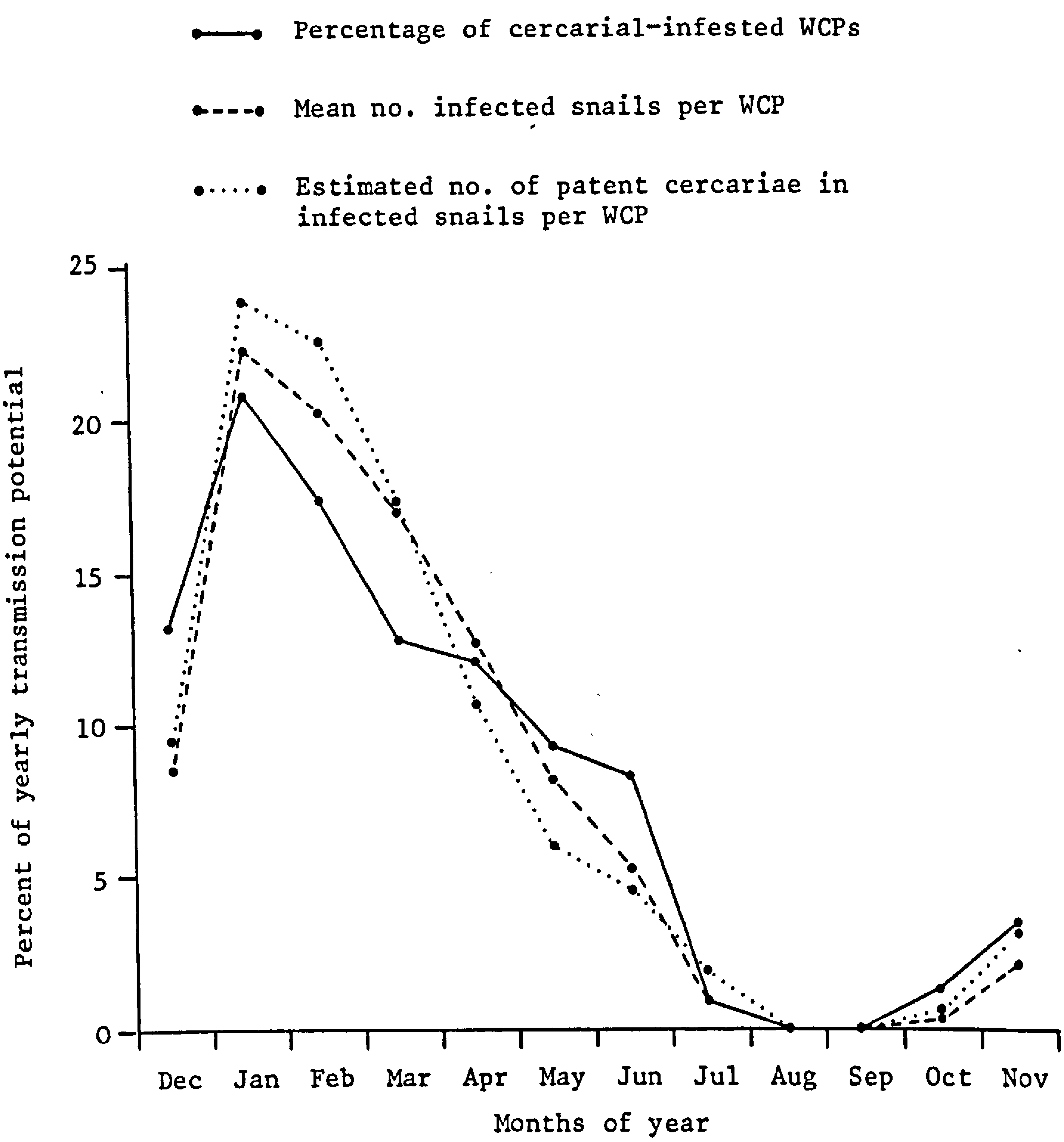


Fig. 18. Comparison of relative monthly indices of transmission potential between 3 methods of analysis.

6.5 PHYSICAL FACTORS AFFECTING TRANSMISSION

6.5.1 Vegetation

Table 20 lists plants and substrates from which total *B. rohlfsi* were collected around the lake, by season, and after 20 months of sampling. Each season, the greatest number of snails was found on *Ceratophyllum* - 31.6% in the early to mid-drawdown season, 73.8% in the low water season, and 22.8% in the flood season. Overall, 42.3% of *B. rohlfsi* were collected from the weed.

In the present study, *Ceratophyllum* was mainly confined to the Afram and Obosum branches. It grew sporadically in the Pru and Mid Volta branches, grew only temporarily in the Dayi and Oti branches, and was absent from the Black Volta and Daka branches. By contrast, the weed was much more widespread in the WHO study area during the project's precontrol sampling period, when it accounted for over 70% of all *B. rohlfsi* collected (Klumpp and Chu, 1977).

The second most important substrate for *B. rohlfsi* in the current study was sticks. Most of these were uprooted cassava stalks, which littered the foreshore of many villages during the second early to mid-drawdown season.

About 8% and 7% of the total snails were found on *Polygonum* and *Paspalum* respectively. Other plants were less commonly observed, and thus harboured fewer snails.

The results showing low percentages of *B. rohlfsi* found in mud, sand, or on stones indicate that it cannot survive well in WCPs without living or dead macrophytic cover. This agrees with results from the WHO project (ibid).

In the WHO study area, fluctuation of *Ceratophyllum* in the littoral zone was a dominant ecological factor in determining levels of transmission potential. It was mentioned earlier (section 4.6) that a strong positive correlation existed between mean density rank of the weed in sampled WCPs and the percentage of times the respective WCPs were found to contain one or more infected *B. rohlfsi*.

Vegetation or substrate from which snails were collected	Number and % of *B. rohlfsi*, by season and overall							
	Dec - Mar,	%	Apr - Jul,	%	Aug - Nov,	%	Total,	%
Ceratophyllum	2164	31.6	1956	73.8	123	22.8	4243	42.3
Sticks	2139	31.3	256	9.7	62	11.5	2457	24.5
Polygonum	714	10.4	29	1.1	78	14.5	821	8.2
Paspalum	668	9.8	27	1.0	30	5.6	725	7.2
Ludwigia	151	2.2	114	4.3	81	15.0	346	3.4
Mud or sand	260	3.8	48	1.8	0	0	308	3.1
Canoes	121	1.8	35	1.3	94	17.4	250	2.5
Alternanthera	125	1.8	5	0.2	41	7.6	172	1.7
Stones	132	1.9	34	1.3	3	0.6	169	1.7
All other	365	5.4	147	5.5	27	5.0	539	5.4
Total	6840	100.0	2651	100.0	539	100.0	10030	100.0

Table 20. Seasonal and total number of *B. rohlfsi* collected around the lake, in relation to type of vegetation or substrate from which collected by man-time sampling, November 1978 - June 1980.

Using the same method of analysis for the same 2 parameters, no such positive correlation emerged from total sampling results in the present study. However, a significant, positive correlation did exist for results confined to the April - July season, when Ceratophyllum was usually the only weed to be found in WCPs.

Figure 19 shows the proportion of *B. rohlfsi* that were collected directly from *Ceratophyllum* during each month of sampling, and how this varied with lake level.

Discussion

The present sampling results confirm 2 observations first made in the WHO project: (1) that populations of *B. rohlfsi* expand and survive best in WCPs containing *Ceratophyllum* and/or emergent weeds; and (2) that without the weed growing in WCPs between April and July, populations of *B. rohlfsi* will contract rapidly after March, and transmission of *S. haematobium* will be naturally depressed until the following November or December.

A new finding in the present research is that even without much emergent vegetation cover in the littoral zone during December to March, large numbers of *B. rohlfsi* can appear in this zone if it is littered with sticks, e.g., cassava stalks.

Fresh cassava stalks and tubers contain cyanide and other juices, which are probably lethal to *B. rohlfsi*. This was observed in the present research from one *ad hoc* lab test and from the observation that *B. rohlfsi* was never found in WCPs that were full of fresh cassava debris. When the lake was rising rapidly in September and October 1979, many cassava farms on the lake's foreshore were inundated. No aquatic snail of any species was seen in cassava-littered WCPs until November, when *B. forskalii* first appeared. By December, inundated cassava stalks had lost their juices and were brittle. From then until March 1980, the cassava stalks were numerous in and around these WCPs, and were covered with algae. *B. rohlfsi* of all sizes (along with egg clutches) colonized the stalks in large numbers. In the same season, 44% of all *B. rohlfsi* collected at that time were picked from this substrate.

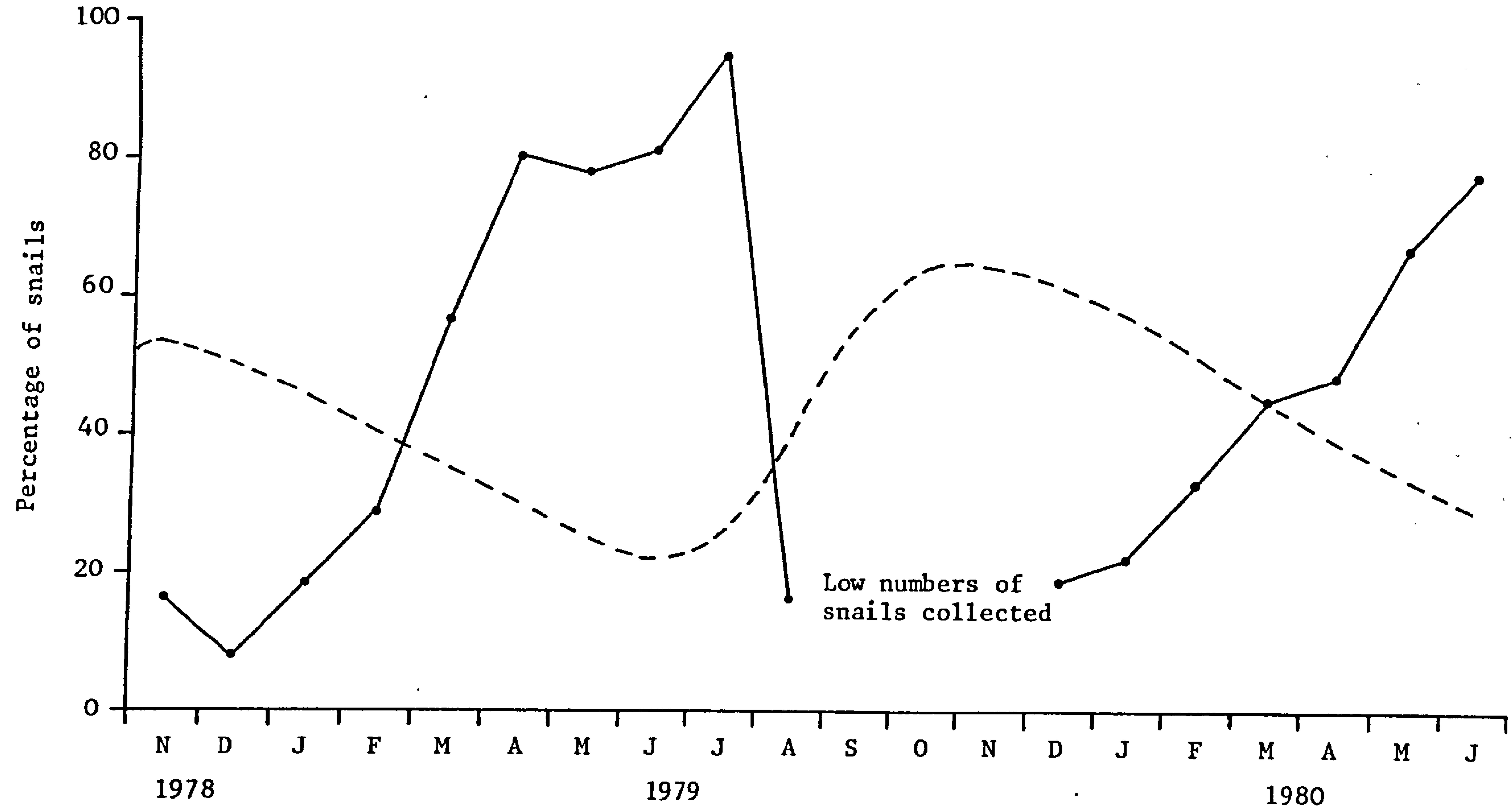


Fig. 19. The percentage of all B. rohlfsi collected each month that were picked directly from Ceratophyllum demersum (solid line), and relative surface elevation of lake (dashed line).

The significance of Polygonum in forming side boundaries around Volta-Lake WCPs from September to March each year (thereby sheltering the WCPs from strong wind and wave action) was first reported in the WHO project (ibid). Between 1978 and 1980, Polygonum was still the main emergent plant growing in and around WCPs, in all lake sections studied. In the December - March season, large populations of B. rohlfsi were commonly found in Polygonum-sheltered WCPs. This finding contradicts the belief of some malacologists that Polygonum senagalense is an effective plant molluscicide because of molluscicidal substances in its seeds.

6.5.2 Shape of WCP in determining transmission potential

As mentioned previously, WCPs in the lake could be divided into 3 basic ecological types based on their shape - being either pocket-shaped, channel-shaped, or wide, open beaches. During the flood and early to mid-drawdown seasons of the lake cycle, the amount of emergent vegetation growing from shore to deep water determined WCP shape. But even in the low water season when little if any emergent vegetation was left in the water, a WCP could be pocket-shaped due to small curvatures of the shoreline.

It was recognized in the WHO project that greatest number of total and infected *B. rohlfsi* could be found in pocket-shaped WCPs (Klumpp and Chu, 1977), but statistical analysis of sampling results between the different WCP-types was not made.

In the present study, statistical tests were made between the 3 groupings of WCPs, and what follows is an assessment of the relative significance of each group in transmission.

As applied below, the term, sample, means 1 man-hour of searching for *B. rohlfsi* in a WCP.

Number of *B. rohlfsi* in each WCP-habitat

Table 21 lists the number of samples taken in each grouping of WCPs, and numbers of *B. rohlfsi* collected.

Of all samples, 526 WCPs appeared as open beaches, 328 as pocket-shaped, and 123 as channel-shaped. The reason for the high number of open beach WCPs in the December - March season was that many sites in the northern sections of the lake contained little or no emergent vegetation in the littoral zone from February to July.

Forty-eight percent of total *B. rohlfsi* and 62% of infected *B. rohlfsi* were collected in pocket-shaped WCPs, and the mean numbers per sample were greatest in these types of WCPs each season. Low numbers of total and infected snails were found in channel-shaped WCPs.

Plate 24.

Pocket-shaped WCP

Plate 25.

Open beach WCP

Plate 26.

Channel-shaped WCP

Table 21. Number of samples, and numbers of *B. rohlfsi* collected in WCPs shaped as pockets, open beaches, and channels.

Group of WCPs	Parameter	Total	Season: Dec-Mar	Season: Apr-Jul	Season: Aug-Nov
Pocket-shaped	No. samples	328	142	66	120
	No. + snails	740	533	178	29
	No. total snails	4785	3401	928	456
	$\bar{x}$ per sample (± s)				
	+ snails	2.3 (±5.8)	3.8 (±6.1	2.7 (±8.5)	0.2 (±1.0)
	total snails	14.6 (±26.5)	24.0 (±32.0)	14.1 (±20.0)	3.8 (±16.7)
Open beaches	No. samples	526	230	249	47
	No. + snails	420	298	122	0
	No. total snails	4680	3078	1580	22
	$\bar{x}$ per sample (± s)				
	+ snails	0.8 (±2.4)	1.3 (±3.2)	0.5 (±1.6)	0 -
	total snails	8.9 (±23.1)	13.4 (±28.9)	6.3 (±18.1)	0.5 (±2.1)
Channel-shaped	No. samples	123	57	15	51
	No. + snails	39	29	10	0
	No. total snails	604	361	143	61
	$\bar{x}$ per sample (± s)				
	+ snails	0.3 (±1.1)	0.5 (±1.4)	0.7 (±1.4)	0 -
	total snails	4.4 (±10.3)	6.3 (±12.1)	9.5 (±16.2)	1.0 (±3.2)

In Table 21, standard deviations of the mean numbers of B. rohlfsi were large. Of the 984 total samples, 592 yielded no snails, and when snails were found, the frequency distribution was further skewed in all 3 types of WCPs. This non-normal distribution precluded null hypothesis testing of mean numbers of infected or total snails per WCP sampled.

The data could be normalized by taking the logarithmic values of individual collections where one or more B. rohlfsi was collected. But testing differences between the log means would not really answer the question of which type of WCP posed the greatest danger for transmission.

The best way to answer the question would be to compare the 3 habitat-types in terms of the following: (1) the proportion of samples in which any B. rohlfsi was found, and (2) the proportion in which infected B. rohlfsi were found.

Proportion of samples with B. rohlfsi

Tables 22 and 23 clearly show that the probability of finding any B. rohlfsi or infected specimens was significantly greater in pocket-shaped WCPs than it was in open beaches or channel-shaped WCPs. By the same measure, there was no significant difference in transmission potential between WCPs shaped as open beaches or channels.

Table 24 compares the proportion of samples with infected snails during the 3 lake seasons. Each season, transmission potential was significantly highest in pocket-shaped WCPs. There were no significant differences in transmission potential between open beaches and channel-shaped WCPs.

Within the pocket-shaped and open-beach groups, most transmission potential existed in December - March, although the drop-off in the April - July season was least significant for pocket-shaped WCPs.

Table 22. Differences between 3 main types of WCPs regarding proportion of samples with any B. rohlfsi.

Type of WCP	No. with snails/ total no. samples	%	χ^2	(Level of signif.)
Pocket-shaped	187/328	57.0		
			52.26	(P <0.001)
Open beach	168/526	32.0		
			0.44	(NS)
Channel-shaped	37/130	28.5		

NS = not significant; P > 0.05

Table 23. Differences between 3 main types of WCPs regarding proportion of samples with infected B. rohlfsi.

Type of WCP	No. with + snails/ total no. samples	%	χ^2	(Level of signif.)
Pocket-shaped	108/328	32.9		
			25.99	(P <0.001)
Open beach	92/526	17.5		
			3.00	(NS)
Channel-shaped	14/130	10.8		

NS = not significant; P > 0.05

Table 24. Proportion of samples with infected B. rohlfsi each season, and chi-square testing between various proportions.

WCP group	Dec-Mar	Apr-Jul	Aug-Nov
Pocket-shaped	75/142 58.2%	23/66 34.8%	10/120 8.3%
Open beaches	58/230 25.2%	34/249 13.6%	0/47 0%
Channel-shaped	10/57 17.5%	4/15 -	0/58 0%
χ^2 values of differences between above proportions			
Pocket-shaped vs. open beaches	27.92***	14.14***	23.82***
Open beaches vs. channel-shaped	1.09 (NS)	1.03 (NS)	-

	Dec-Mar vs. Apr-Jul	Apr-Jul vs. Aug-Nov
Pocket-shaped	5.13*	18.74***
Open beaches	9.57**	5.96***
Channel-shaped	1.35(NS)	11.62***

*** = P <0.001; ** = P <0.01); * = P <0.05; NS = not significant, P>0.05

Discussion

Although the above grouping of WCPs appears somewhat arbitrary, experience has shown that in the Volta Lake, a WCP that is bounded on the sides by emergent vegetation and is pocket-shaped provides the best environment for survival and expansion of B. rohlfsi. Too much emergent vegetation surrounding a WCP causes stagnant water and pollution which seems to be inimical to expansion of B. rohlfsi populations; human water contact is also less intense. Open beach WCPs are usually devoid of emergent weeds after February, and unless Ceratophyllum is present, B. rohlfsi cannot survive wave action in these sites.

From the above analysis, a case can be made for emphasizing weed clearance as a preventative measure to control transmission. Clearing operations would have to be undertaken with knowledge of the ecology. For example, simply widening a channel-shaped WCP by pulling-up emergent weeds would probably increase transmission by turning these points into pocket-shaped WCPs. However, complete removal of emergent weeds around either pocket-shaped or open-beach WCPs should be very effective in reducing transmission potential. Removing all Ceratophyllum from all WCPs where it grows is also essential, but experience has shown that it is virtually impossible to keep WCPs free of Ceratophyllum where it grows in large off-shore masses (Klumpp, Rafatjah, and Chu, unpublished data).

Applying herbicides or uprooting weeds by hand across a village drawdown area at low water level might be the most efficacious way of controlling transmission (for up to a year) after the subsequent flooding. Herbiciding an entire drawdown area before flooding was tried with some success at the resettlement village of Ampem in 1969 (Pierce, unpublished USAID report, 1971). In that trial, no emergent weed growth appeared in any WCP in the treated area for over 1 year. However, washed-in emergent weeds and Ceratophyllum was a problem, and these weeds had to be removed periodically by hand.

Another way of keeping a drawdown area free of emergent weeds would be to encourage farming of the foreshore. The author has observed that when such crops as maize, sweet potatoes, ocra, egg plants, and tomatoes are planted near the receeding shoreline from December - June, emergent vegetation is greatly reduced in and around WCPs after subsequent flooding, and in the following December - March season, the WCPs are likely to be open beaches. However, as discussed in the previous section, planting cassava in lower parts of the drawdown area could be dangerous for transmission if the stems are not removed before flooding.

6.5.3 Geographical location of WCPs in determining transmission potential

In this section, snail sampling results will be analysed in the same way as in the previous section, but to test whether differences in geographical location of WCPs was a factor in determining transmission potential.

From experience at the Volta Lake, the author observed that prevalence rates and egg counts among humans (as well as numbers of *B. rohlfsi* collected) were generally highest in villages located along narrow stream inlets and were consistently lowest in villages located along wide, open sections of the lake, regardless of short-term fluctuation in vegetation growth.

In the present analysis, the 58 sampled WCPs in the 39 villages have been grouped into 3 geographical categories: (1) sheltered WCPs - located at stream inlets or coves, where the lake was less than 300 m across; (2) exposed WCPs - located along a straight or convex-shaped shoreline where the lake was either over 3 km wide, or, if less than 3 km wide (but over 2 km wide), where little or no emergent vegetation grew in the water; and (3) semi-sheltered WCPs - all WCPs that did not fit into the above 2 categories, and normally where the lake section was between 0.5 - 2 km wide. Nineteen WCPs were in the sheltered category, 24 were grouped as semi-sheltered, and 15 were exposed.

Plate 27. <u>Sheltered WCP</u>: at inlets and narrow coves; least wind and wave action.

Plate 28. <u>Semi-sheltered WCP</u>: at wide coves and other sections exposed to moderate wind and wave action.

Plate 29. <u>Exposed WCP</u>: at wide, open sections of lake where wind and wave action is greatest.

Number of B. rohlfsi in each geographical location

The results in Table 25 indicate that 58% of all B. rohlfsi and 61% of all infected specimens were collected from WCPs that were in sheltered areas. About 32 - 24% of total and infected snails respectively were found in semi-sheltered locations, while only 8% respectively came from exposed WCPs. In every season, the mean number of infected snails found in sheltered WCPs were at least 1.8 times higher than in semi-sheltered WCPs, and at least 4 times greater than in exposed WCPs. As discussed in the previous section, there were so many samples with no snails that null hypothesis testing between mean numbers of snails per WCP in each category would not be suitable statisitically.

Proportion of samples with total and infected B. rohlfsi

The chi-square values in Tables 26 and 27 confirm that transmission potential was greatest in WCPs at sheltered locations and was insignificant in exposed WCPs.

In Table 28, the proportion of samples with infected snails are given for the 3 lake seasons. As expected, there was no significant difference in this measure of transmission potential between sheltered and semi-sheltered WCPs in the December to March seasons - emergent weeds bounded most WCPs in this season regardless of location, and in general provided equally effective shelter against wave action. But in the April - July season when emergent weed cover was gone, there was no natural shield against heavy wave action in exposed and semi-sheltered locations, and transmission was significantly greater in naturally sheltered WCPs.

Table 25. Number of samples, and numbers of B. rohlfsi collected in WCPs that were at sheltered, semi-sheltered, or exposed shores.

Group of WCPs	Parameter	Total	Season: Dec-Mar	Season: Apr-Jul	Season: Aug-Nov
Sheltered	No. samples	336	144	120	72
	No. + snails	734	464	244	26
	No. total snails	5796	3825	1535	436
	$\bar{x}$ per sample (± s)				
	+ snails	2.2 (±5.6)	3.2 (±5.8)	2.0 (±6.5)	0.4 (±0.1)
	total snails	17.2 (±31)	26.6 (±39)	12.8 (±19)	6.1 (±21)
Semi-sheltered	No. samples	399	177	127	95
	No. + snails	372	309	60	3
	No. total snails	3408	2295	1019	94
	$\bar{x}$ per sample (± s)				
	+ snails	0.9 (±2.7)	1.8 (±3.6)	0.5 (±1.7)	0.03 (±0.2)
	total snails	8.5 (±20)	13.0 (±22)	8.0 (±22)	1.0 (±3)
Exposed	No. samples	249	108	83	58
	No. + snails	93	87	6	0
	No. total snails	826	720	97	9
	$\bar{x}$ per sample (± s)				
	+ snails	0.4 (±2.0)	0.8 (±2.9)	0.1 (±0.6)	0 -
	total snails	3.3 (±12)	6.7 (±17)	1.2 (±6)	0.2 (±1)

Table 26. Differences between 3 main geographical location of WCPs regarding proportion of samples with any B. rohlfsi.

Location of WCP	No. with snails/ total no. samples	%	χ^2	(Level of signif.)
Sheltered	210/336	62.5		
			42.49	(P <0.001)
Semi-sheltered	152/399	38.1		
			46.82	(P <0.001)
Exposed	32/249	12.8		

Table 27. Differences between 3 main geographical location of WCPs regarding proportion of samples with infected B. rohlfsi.

Location of WCP	No. with + snails/ total no. samples	%	χ^2	(Level of signif.)
Sheltered	117/336	34.8		
			18.81	(P <0.001)
Semi-sheltered	81/399	20.3		
			22.11	(P <0.001)
Exposed	16/249	6.4		

Table 28. Proportion of samples with infected B. rohlfsi each season, and chi-square testing between various proportions.

Location of WCP	Dec-Mar	Apr-Jul	Aug-Nov
Sheltered	65/144 45.1%	44/120 36.7%	8/72 11.1%
Semi-sheltered	64/177 36.2%	15/127 11.8%	2/95 2.1%
Exposed	14/108 13.0%	2/83 2.4%	0/58 -

χ^2 values of differences between above proportions	Dec-Mar	Apr-Jul	Aug-Nov
Sheltered vs. semi-sheltered	2.30 (NS)	18.14***	4.41*
Semi-sheltered vs. exposed	17.00***	4.77*	0.14 (NS)

	Dec-Mar vs. Apr-Jul	Apr-Jul vs. Aug-Nov
Sheltered	1.60 (NS)	19.74***
Semi-sheltered	21.54***	5.93*
Exposed	5.50*	0.22 (NS)

*** = P < 0.001; * = P < 0.05; NS = not significant, P > 0.05

Discussion

Evidence will be presented later to show that relative to other Volta-Lake villages, human prevalence rates and egg counts of *S. haematobium* were significantly lower in villages at exposed sections of the lake. At Lake Kariba, Hira (1970) noticed that schistosome transmission seemed to be greatest in villages at inlets and lowest in villages by the open lake. Since the present results show that transmission hardly existed in WCPs at exposed lakeside villages, planners of settlements at large man-made lakes should endeavour to situate resettlement communities at sites where the lakeshore is relatively straight and the expanse of water is wide. Taking this simple realization into account before allowing human settlement should result in a cost/effective way of limiting schistosome transmission and morbidity.

6.6 A STUDY OF THE GROWTH, SURVIVORSHIP, AND FECUNDITY OF *B. ROHLFSI* IN A FIELD LABORATORY

6.6.1 Introduction

Although McCullough (1962b) studied aspects of the egg laying capacity of *B. rohlfsi* in Ghana, no detailed study of the growth rate, survivorship, or fecundity of the Volta-Lake strain of the species has been previously published.

An experiment was carried out at Agbenoxoe in 1980 to gain information on these parameters and to determine the intrinsic rate of natural increase, "r", of *B. rohlfsi* in 2 different aquatic media which simulated a favourable and less favourable environment in the Volta Lake - (1) lake water plus a mud substratum (plus food) and (2) lake water only (plus food).

Three unsuccessful attempts were made by the author to collect data on snail growth, survivorship, and fecundity by direct sampling of natural populations of *B. rohlfsi* in the Volta Lake. In each case, there were sudden die-offs of the snails before adequate information could be collected (once by lake regression stranding *Ceratophyllum* and the target snail population on shore, once by lake flooding, and once by a storm destroying the habitat). Snail migration caused by shifting *Ceratophyllum* was another problem, as was trying to distinquish egg clutches and baby snails of *B. rohlfsi* from those of sympatric *B. forskalii*.

6.6.2 Materials and methods

The experimental conditions are summarized in Table 29.

The laboratory was a screened porch with a bamboo and thatch roof. To prevent accidental loss, or predation by mice and shrews, each snail container was covered with a perforated snap-on lid.

Fresh lake water was used throughout the experiment and changed 4 times every fortnight. The first change was made when the snails were about 2 mm in shell height.

Table 29. Experimental conditions.

Item		Description	
1.	Course of experiment	8/2/1980 - 5/8/1980	
2.	Origin of breeding snails	Volta Lake	
3.	Age at which baby snails were transferred to snail containers	1 day-old	
4.	Type of snail containers	Clear plastic	
5.	Capacity of each container (ml)	875	
6.	Water temperature recorded	Minimum - maximum	
7.	Frequency of temperature recording	Daily	
		Lake water only	Lake water + mud
8.	Volume of lake water (ml)	800	750
9.	Volume of mud substratum (ml)	-	50
10.	Number of F1 starting snails	32	50
11.	Number of snails per container	2	2
12.	Snail food		
	< 3 week-old snails	Tetramin	Tetramin
	> 3 week-old snails	Dried lettuce	Dried lettuce
13.	Frequency per forthnight of changing water, counting, and removing snail eggs	4x	4x

For the containers with mud, the 50 ml of mud rose about 2 cm from the bottom of each container, and was maintained at this level by periodic addition of small amounts of extra mud when repeated water changes depleted the supply. The mud was collected from the Volta Lake, strained, and dried before use. After the containers with mud were first filled with lake water, the water was allowed to clarify for 12 days before the baby snails were added.

Each cohort originated from 2 large, plastic breeding bowls, one with a mud substratum. When the snails hatched, 1 - 2 day-old specimens were carefully placed in the appropriate containers, using an artist's brush. The first measurements of shell height were made when the snails were 3 - 4 days old, by sacrificing a random sample of 30 extra snails from each breeding bowl, and doing the measurements on a microscope with a measuring scale. All subsequent measurements were made with vernier calipers, after briefly removing each pair of snails from their numbered container.

Except for a few cases of egg deposition on the shells of B. rohlfsi, all eggs were laid on the sides of the clear plastic containers and could be counted easily with a magnifying glass. When counting was finished, water was removed, the sides of the containers wiped clean with a paper towel, and any dead snail removed.

When a snail died, another snail was taken from the highest numbered replicate of the same group and added to the appropriate container to maintain 2 snails per container. If the highest numbered container ended up with 1 snail, it was excluded for fecundity counts until 2 snails were once again present.

6.6.3 Results

Water temperature

The mean mimimum values for each fortnight ranged from 24.2° - 26.0°C, while the mean maximum temperatures declined steadily from 33.6°C during the first fortnight after hatching to 28.7°C after 12 fortnights. The highest daily water temperature recorded was 34.5°C, the lowest, 22.0°C. The overall mean temperature ranged from 28.8° - 29.8°C during the first 5 fortnights, dropped to under 27°C by the 9th fortnight (start of rainy season), and stayed near 26.6°C until the experiment ended (Figure 21). The above values fell within the range of water temperature recorded in Volta-Lake WCPs during the WHO project (Figure 20).

Initial incubation period

The minimum time for the F1 snails to hatch was 6 days.

Growth rates

These can be seen in Figure 21. At 3 - 4 days of age, mean shell height of the snails in lake water only ("lake water" cohort) was 1.26 mm (±.189 mm) compared to 1.29 mm (±.151 mm) for the snails in lake water plus a mud substratum ("mud" cohort). In all subsequent measurements, the "mud" snails were significantly larger than the "lake water" snail (t test applied). After 8.5 fortnights (119 days), almost 70% of the "lake water" snails had died; their mean shell height at that time was 6.5 mm, compared to 8.0 mm for the "mud" cohort which lived beyond 12 fortnights.

The minimum shell height of *B. rohlfsi* acceptable for collection in the field was approximately 3 mm. From the growth curves, the "mud" cohort reached that size (3.0 mm) in 14 days compared to 23 days for the "lake water" cohort. The mean shell height of all 10,030 field-collected *B. rohlfsi* was 5.0 mm. To reach the same mean size required 36 days for the "mud" snails and 53 days for the "lake water" snails.

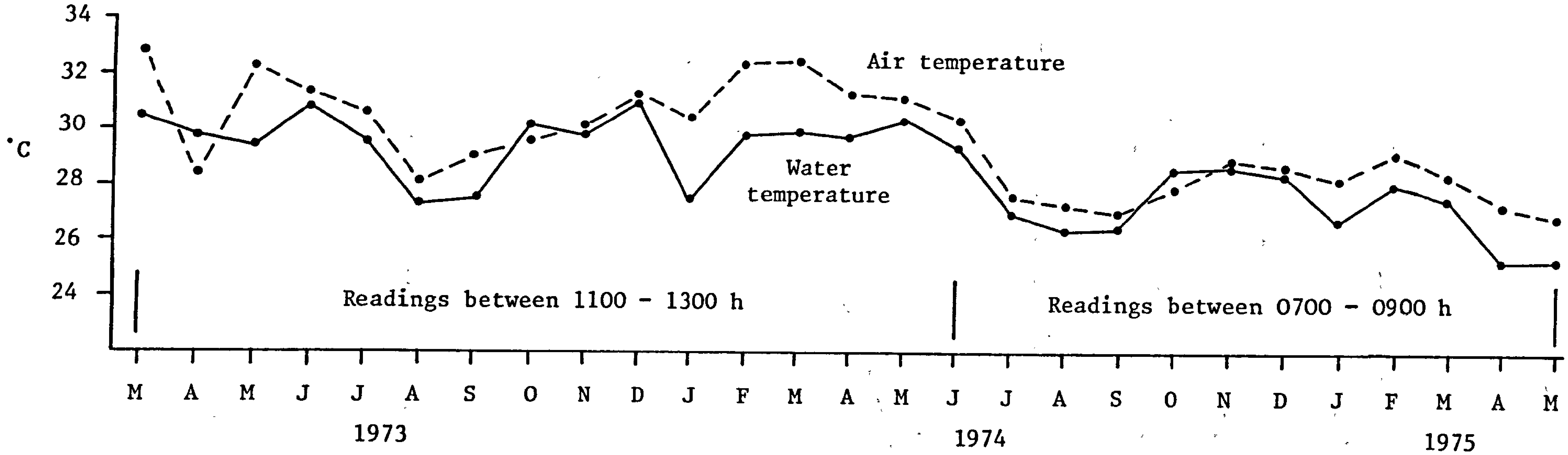


Fig. 20. Air and water temperatures in WCPs in the WHO study area, 1973 - 1975. Each value represents the mean of readings taken in 8 different WCPs each month. All water temperatures were taken 5 - 10 cm below the water surface (original data).

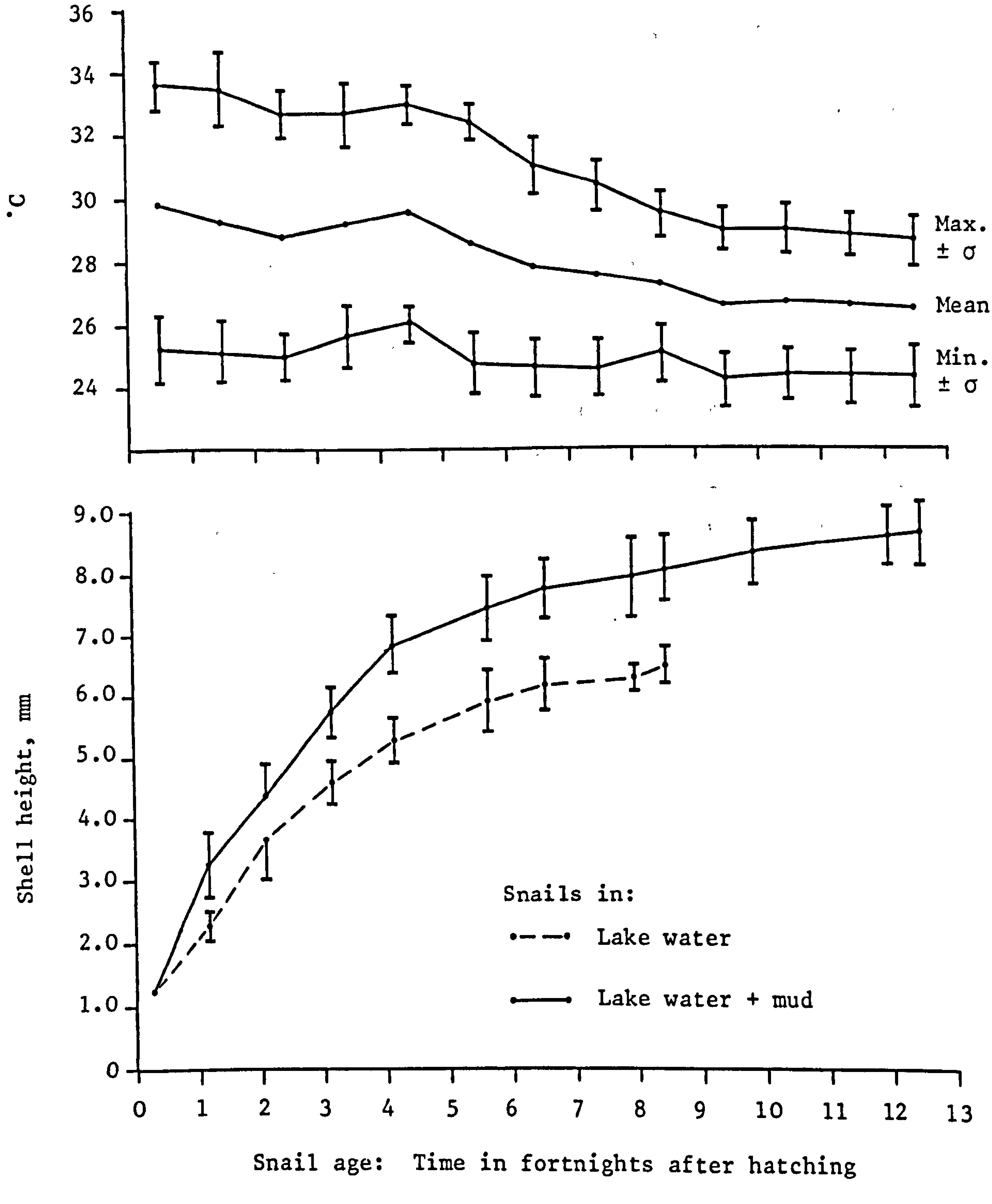


Fig. 21. Growth rate of B. rohlfsi in 2 laboratory conditions, and mean fortnightly values of maximum, minimum, and overall water temperature during course of experiment.

Ecological life tables (Table 30).

The proportion of the newly-hatched snails that survived through each successive fortnight (survivorship, l_x) was far better for the cohort raised in lake water plus mud. At 12.5 pivotal fortnights of age, all of the "lake water" cohort died, while 60% of the "mud" snails were still alive.

Some of the "lake water" snails began laying eggs after only 20 days of age - 26 days from "egg to egg". The earliest eggs laid by the "mud" cohort was 31 days after hatching.

The average number of eggs laid per snail per fortnight (fecundity, m_x) increased quickly for the "lake water" cohort and reached a peak of 121.4583 at 4.5 pivotal fortnights before dropping-off. Peak fecundity in the "mud" cohort was slightly higher, but was not reached until 6.5 pivotal fortnights. After that, m_x values for the snails with mud remained near the peak level until the experiment ended.

R_o, R, r, and T parameters (Table 31)

The incomplete net reproductive rate (R_o) from Table 30 was 1.8 times higher for the "mud" cohort than the complete results for the "lake water" cohort. But because of earlier onset of egg laying and higher fecundity through the first 5.5 pivotal fortnights, the finite (R) and intrinsic (r) rates of natural increase were 1.7 and 1.5 times higher repectively for the "lake water" snails vs. the "mud" snails. This produced a shorter mean generation time (T) for the "lake water" snails.

Pivotal age in fortnights	Snails in lake water + food			Snails in lake water + mud + food		
	l_x	m_x	$l_x m_x$	l_x	m_x	$l_x m_x$
0	1.0000	0	0	1.0000	0	0
0.5	.9688	0	0	1.0000	0	0
1.5	.9688	4.4194	4.2815	1.0000	0	0
2.5	.8125	28.8462	23.4375	1.0000	0.4400	0.4400
3.5	.7500	76.2500	57.1875	.9600	7.3542	7.0600
4.5	.7500	121.4583	91.0938	.9600	76.3125	73.2600
5.5	.6250	115.6000	72.2500	.8800	83.0909	73.1200
6.5	.5000	105.0000	52.5000	.8000	123.0000	98.4000
7.5	.3750	86.9167	32.5938	.7800	106.6154	83.1600
8.5	.3125	65.9000	20.5938	.7600	118.7105	90.2200
9.5	.1875	74.3333	13.9375	.7000	88.0000	61.6000
10.5	.1250	81.2500	10.1562	.6800	115.5294	78.5600
11.5	.0938	76.3333	7.1562	.6200	118.0968	73.2200
12.5	0	0	0	.6000	102.8333	61.7000

Table 30. Ecological life table of each cohort of B. rohlfsi, showing age-specific survivorship (l_x), fecundity (m_x), and the product, $l_x m_x$.

Table 31. Calculated values per fortnight of the net reproductive rate (R_o), finite rate of increase (R), intrinsic rate of natural increase (r), and mean generation time (T), from life table data in Table 30.

Parameter	Snails in lake water	Snails in lake water plus mud*
Net reproductive rate (R_o) $= \Sigma l_x m_x$	385.1878	> 700.7400
Finite rate of increase (R) $= e^r$	5.1642	2.9923
Intrinsic rate of natural increase (r) $= \Sigma e^{-rx} l_x m_x \rightarrow 1$	1.6418	1.0960
Mean generation time (T, in fortnights) $= \log_e R_o (1/r)$	3.6263	5.9782

* Experiment ended after 12 fortnights, but sufficient data available for R, r, and T to be calculated accurately.

Discussion

The fortnighly r values of 1.6418 for *B. rohlfsi* in lake water and 1.0960 for the cohort maintained in lake water with mud were higher than most results from other lab studies known by the author where r values were obtained for schistosome-bearing snails (Table 32).

Recent analysis of an unpublished life-table study of *B. rohlfsi* by the author at Anyaboni in 1975 - 1976 produced r values (per fortnight) of 1.091 for a cohort of snails in lake water plus mud and 1.563 for a cohort raised in stream water, where 6 snails were maintained per 875 ml container and where mean fortnightly water temperatures ranged from 23.5° - 26.6° C. For South African *Bulinus tropicus* of veterinary importance, De Kock and Van Eeden (1976) calculated fortnightly r values as high as 3.63 - 3.66 for replicates of snail cohorts raised in a constant 26° C; for the same species at 21° C, Prinsloo and Van Eeden (1969) calculated r to be 1.98.

Any organism with a large r value has been characterized in ecological terms as "opportunistic", being able to expand its population quickly when conditions are good and unable to maintain an equilibrium population from season to season (MacArthur, 1960). In the unstable habitat of the Volta Lake, *B. rohlfsi* fits this category - maximizing its potential to expand its population quickly at the start of each drawdown period, but unable to maintain an equilibrium population after 3 - 4 months of lake regression.

The effect of a mud substratum in increasing the growth rate and survivorship of snails has been described by many researchers, including Cowper (1946), Standen (1949), Moore et al. (1953), Liang (1974), and Chu, Massoud, and Arfaa (unpublished manuscript).

In the present experiment, it was noted that *B. rohlfsi* in containers with mud never developed a fungus which occasionally enveloped the shells of snails in lake water only, and which had to be gently brushed-off infested shells to prevent the snails from dying.

Snail species	Origin	Aquatic medium	Water temperature, °C 18	19	20	22.5	23.5	25	27	27.5	28	30	Reference
O. quadrasi	Philippines	water	-	-	-	-	-	-	-	.18	-	-	Hairston, 1973
B. truncatus	Iran	water	-	-	-	-	.53[a]	-	-	-	-	-	Chu et al. (unpublished data)
		water + mud	-	-	-	-	.69[a]	-	-	-	-	-	
B. alexandrina	Egypt	water	-	-	.39	-	-	1.15	-	.78	-	.20	Hairston, 1973
B. (P.) globosus	Zimbabwe	water	.22	-	-	.47		.66	.60	-	-	-	Shiff, 1964
B. pfeifferi	Zimbabwe	water	.24	-	.47	.46	-	.48	.44	-	-	-	Shiff & Husting, 1966; Shiff & Garnett, 1967
B. pfeifferi	Zimbabwe	water	-	-	-	-	-	.72[b]	-	-	-	-	Harrison et al., 1970
B. pfeifferi	Tanzania	water	-	.25	-	-	-	.86	-	-	-	-	Sturrock, 1966
B. glabrata	Puerto Rico	water	-	-	.88	-	-	1.72	-	-	-	.20	Hairston, 1973
B. glabrata	St. Lucia	water	-	-	.47	-	.85	.88	-	-	-	.67	Sturrock & Sturrock, 1971
B. rohlfsi	Ghana	Lake water	-	-	-	-	-	-	-	-	1.64[d]	-	Present study & unpublished results by author
		Stream water	-	-	-	-	-	1.56[c]	-	-	-	-	
		Lake water + mud	-	-	-	-	-	1.09[c]	-	-	1.10[d]	-	

a,c,d = mean temperature ranges as follows (°C): a = 21°- 25°; c = 23.6°- 26.6°; d = 26.6°- 29.8°; b = max. value at 35 mg/l $CaCO_3$.

Table 32. Values of intrinsic rate of natural increase (per fortnight) for snail hosts of human schistosomes in various laboratory conditions.

Although direct evidence was lacking, survivorship among the "mud" snails could have been helped by the mud acting as an insulation to keep temperatures cooler than the ambient water temperature actually recorded. In Iran, Chu (personal communication) found healthy B. truncatus in bottom mud of shallow ponds when surface water temperature approached 40°C. In the WHO project, B. rohlfsi was found under sticks, logs, leaves, or in the muddy bottoms of WCPs where surface water temperature exceeded 36°C.

In the present experiment, the high water temperature did not seem to suppress fecundity. For some snails which are indiginous to hot climates, a water temperature of 30°C may be necessary to stimulate full breeding activity (Brown, 1980).

Despite the greater suvivorship and growth rate of snails with a mud substratum, the onset of egg laying was later and fecundity (m_x) levels were lower than in the "lake water" cohort through the first 5 fortnights. In the same period, the overlying water in all containers with mud was turbid. Harrison and Farina (1965) found that high turbidity caused by illite and sericite could inhibit depostion of viable eggs of B. globosus and B. pfeifferi in Zimbabwe. Normal egg deposition and hatching was greatly enhanced for B. pfeifferi when the water was clarified by centrifugation.

Summary

The results of the experiment indicate that for B. rohlfsi in the Volta Lake:

(1) The minimum value of r per fortnight is presumed to be at least 1.10 each year from November to May.

(2) The minimum mean generation time could be as low as 3.5 fortnights.

(3) The minimum egg to egg cycle from one generation to the next could be as low as 26 days.

(4) Greatest fecundity probably occurs in the lake's littoral zone where turbidity is low, but largest and oldest snails probably occur in sheltered areas where the lake bottom contains some mud.

(5) Any seasonal variation in the snail's growth rate, survivorship, or fecundity would not be expected from normal seasonal differences in water temperature per se, since temperature variation in the littoral zone is slight throughout the year.

6.7 SIZE AND AGE-SPECIFIC INFECTION RATES OF S. HAEMATOBIUM IN B. ROHLFSI

6.7.1 Introduction

In this section, analysis is made on size and age-specific infection rates of S. haematobium in B. rohlfsi collected from the lake. It is also a prelude to understanding the mathematical model in the next section, which attempts to describe accurately the dynamics of S. haematobium transmission from man to B. rohlfsi in the Volta Lake.

6.7.2 Materials and methods

All B. rohlfsi collected from WCPs were measured to the nearest 0.5 mm before being crushed and examined for patent and prepatent S. haematobium cercariae. One particular assistant performed almost all measurements, using calipers and a measuring scale.

6.7.3 Results

Prevalence by shell height

Figure 22 presents the overall snail infection rates by 0.5 mm grouping of shell height along with the size frequency distribution of the collected snails. From the shape of the distribution, there must have been a consistent, even-number bias in the shell height measurements. But due to the large number of snails in all 0.5 mm classes of shell height from 3.0 - 8.0 mm, the observed percentages of patent and prepatent infections can be viewed with confidence.

There was no change in the percentage trends when shell height measurements were grouped to the nearest 1.0 mm. The latter grouping produced a smoother frequency distribution. But the 0.5 mm grouping was preferred for subsequent analysis of infection rates because it provided more detail.

In Figure 22, the percentages of patent cercarial infections followed an "s-shaped" curve (fitted by eye) - increasing slowly (5 - 7%) in snails from 3.0 - 4.5 mm, increasing rapidly (10 - 52%) in snails from 5.0 - 9.0 mm, and then dropping (32%) in all 31 snails that were 9.5 mm or larger. In contrast, the percentage of prepatent infections remained almost constant between 3.0 - 7.0 mm, and dropped to 0% in snails 8.5 mm or larger.

The shapes of the above percentage curves are consistent with results from the WHO study area (Klumpp and Chu, 1977) and agree qualitatively with results of Pflüger (1976) involving S. mansoni infections in B. pfeifferi in Madagascar (one of few similar analyses of this kind). For S. mansoni in B. pfeifferi in Kenya, Sturrock, Karamsadkor, and Ouma (1979) observed that "the 'patent' infection rate was not correlated to the 'prepatent' infection rate".

The overall and seasonal breakdown of patent S. haematobium infections by shell height is given in Table 33.

It should be reiterated that in comparison with other field studies around the world, the overall percentage of patent infections in Volta-Lake B. rohlfsi was one of the highest levels (if not the highest) ever recorded for a broad endemic area.

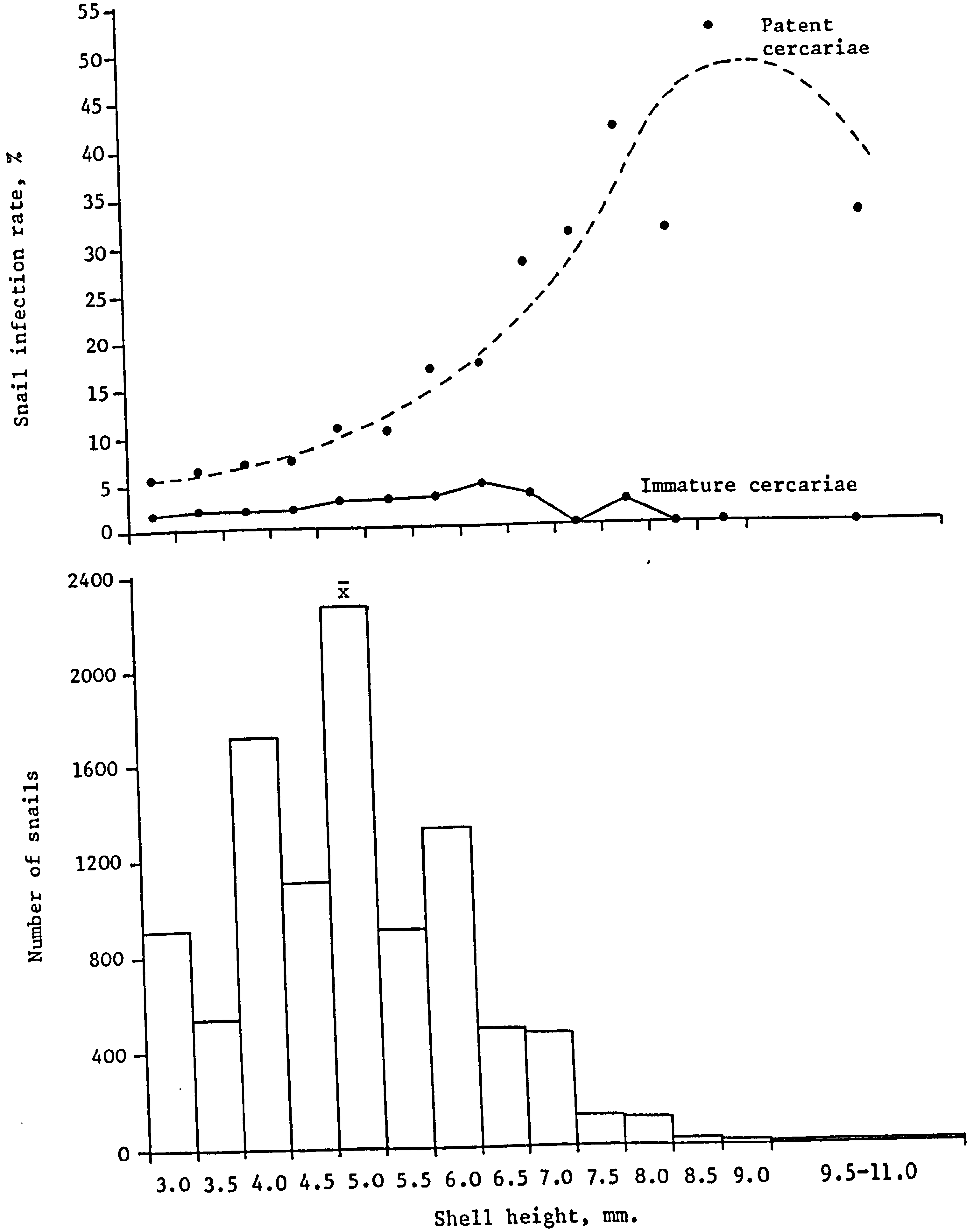


Fig. 22. Size frequency distribution of 10,030 field-collected *B. rohlfsi*, and the size-specific percentage with patent or immature infections of *S. haematobium* cercariae.

Table 33. Number and percent of patent S. haematobium infections in B. rohlfsi over total number of B. rohlfsi collected, by 0.5 mm intervals of shell height.

Shell height (mm)	Season						Total %
	Dec-Mar	%	Apr-Jul	%	Aug-Nov	%	
3.0	24/483	5.0	26/335	7.8	1/84	1.2	5.6
3.5	14/287	4.9	19/203	9.4	2/48	4.2	6.5
4.0	65/1012	6.4	58/632	9.2	1/71	1.4	7.2
4.5	53/743	7.1	28/306	9.2	1/49	2.0	7.5
5.0	173/1595	10.8	84/596	14.1	0/79	0	11.3
5.5	68/665	10.2	26/205	12.7	0/30	0	10.4
6.0	174/987	17.6	42/249	16.9	6/84	7.1	16.8
6.5	72/411	17.5	8/46	17.4	3/28	10.7	17.1
7.0	113/393	28.8	12/51	23.5	4/22	18.2	27.6
7.5	36/107	33.6	2/8	25.0	2/15	13.3	30.8
8.0	43/95	45.3	4/12	33.0	3/13	23.1	41.7
8.5	8/20	40.0	1/7	-	1/5	-	31.2
9.0	10/16	62.5	0	-	2/7	-	52.1
9.5 +	7/26	26.9	0/1	-	3/4	-	40.7

Conversions of shell height measurements into intervals of snail age

Estimated, average field growth curves for Volta-Lake *B. rohlfsi* in different seasons and conditions are shown in Figure 23. These were constructed from results of 5 sets of laboratory studies on snail growth (1975 - 1976 at Anyaboni; 1980 at Agbenoxoe) and from all relevant field data where a distinct mode of *B. rohlfsi* of a narrow size range was found in a WCP after few or no snails were collected from the same WCP at the last, previous sampling. Good agreement was recorded between lab and field data on snail growth up to about 6.0 mm; after that, field snails grew at a faster rate, probably due to less crowding and pollution than in the laboratory containers. The field data were used to estimate snail size beyond 6.0 mm.

The different growth curves reveal that *B. rohlfsi* grew most rapidly in the high transmission season and equally so in the flood season, although the latter period applied mainly to November. The slowest seasonal growth rate occurred in the open beach season. The worst conditions for snail growth occurred in WCPs where little mud or vegetation existed and where *S. haematobium* transmission was intense. Such a situation existed at Bridgeanu-Ahenkro in the Obosum branch. Out of 348 snail collected in the village, only 2 were larger than 6.0 mm in shell height.

Due to slow snail growth after shell height reached 6.0 - 7.5 mm, the growth curves were reliable only up to the following points (±2.5 mm): curves A and B, 8.5 mm; curve c, 7.0 mm; and curve D, 6.0 mm. These were the final mid points used in subsequent conversions of shell height into snail age.

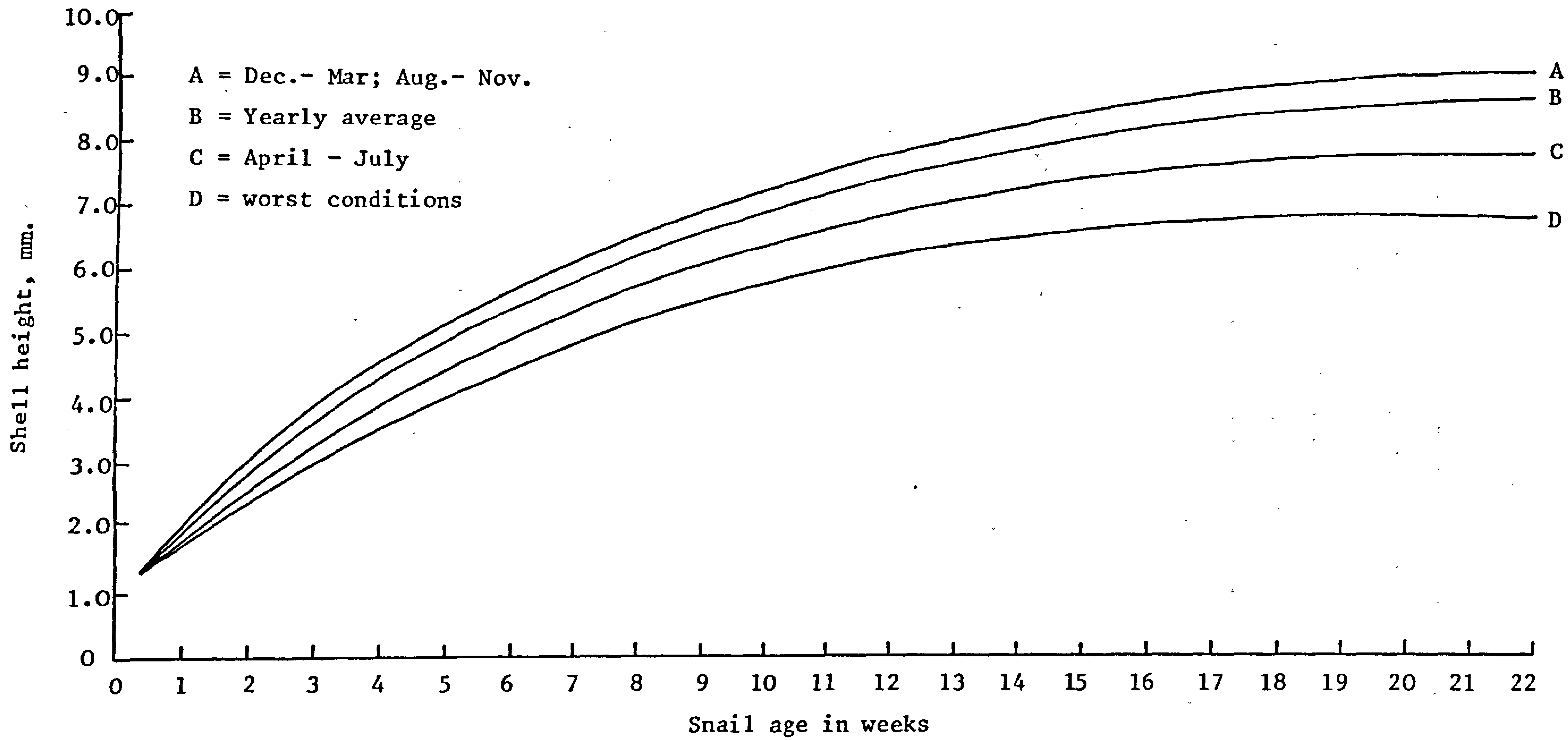


Fig. 23. Estimated field growth rates of Volta-Lake _B. rohlfsi_ in different seasons and conditions.

Age-specific infection rates of S. haematobium in B. rohlfsi

In Figure 24, overall size-specific infection rates of patent S. haematobium cercariae in B. rohlfsi are shown for each lake season. Each histogram represents the percentage of infected snails in each successive 0.5 mm interval of shell height but converted to an age interval from the appropriate growth curve in Figure 23. The earliest age interval corresponds to a shell height of 3.0 mm (± .25 mm) and the oldest to a mid point of shell height (± .25 mm) just below where the growth curve becomes unreliable.

A quick inspection of Figure 24 shows that infection rates rose steadily with increasing snail age in the high transmission season, started off high and then increased slowly in the open beach season, and was lowest in the low transmission season.

The histograms imply that in the high transmission season, snails were exposed to the highest force of infection. In the open beach season, snails seemed to be exposed to a high force of infection, as evidenced by the high infection rates in young snails; but it seemed as if natural snail mortality and mortality caused by the infection were high for all snail ages which reduced numbers of infected snails with increasing snail age. In the low transmission season, the force of infection was either irregular in young snails, or led to greater mortality in this group. The latter explanation seems more likely.

In each season, it seemed as if mortality caused by the infection was most significant in snails between 2 and 6 weeks of age. This probably explains the flat shape of each curve in this age span.

One anomaly in Figure 24 is that the observed onset of patent infections corresponded to a mean snail age ranging from 2 - 2.5 weeks. The problem is that the growth curves were based on growth rates of uninfected snails. The youngest snails with patent infections (3.0 mm) were probably at least 16 days old but had their growth retarded by S. haematobium.

In the WHO study area, Chu (1978) found that the minimum prepatency period of S. haematobium in B. rohlfsi (time from miracidial penetration to first shedding) was 21 days when snails were left

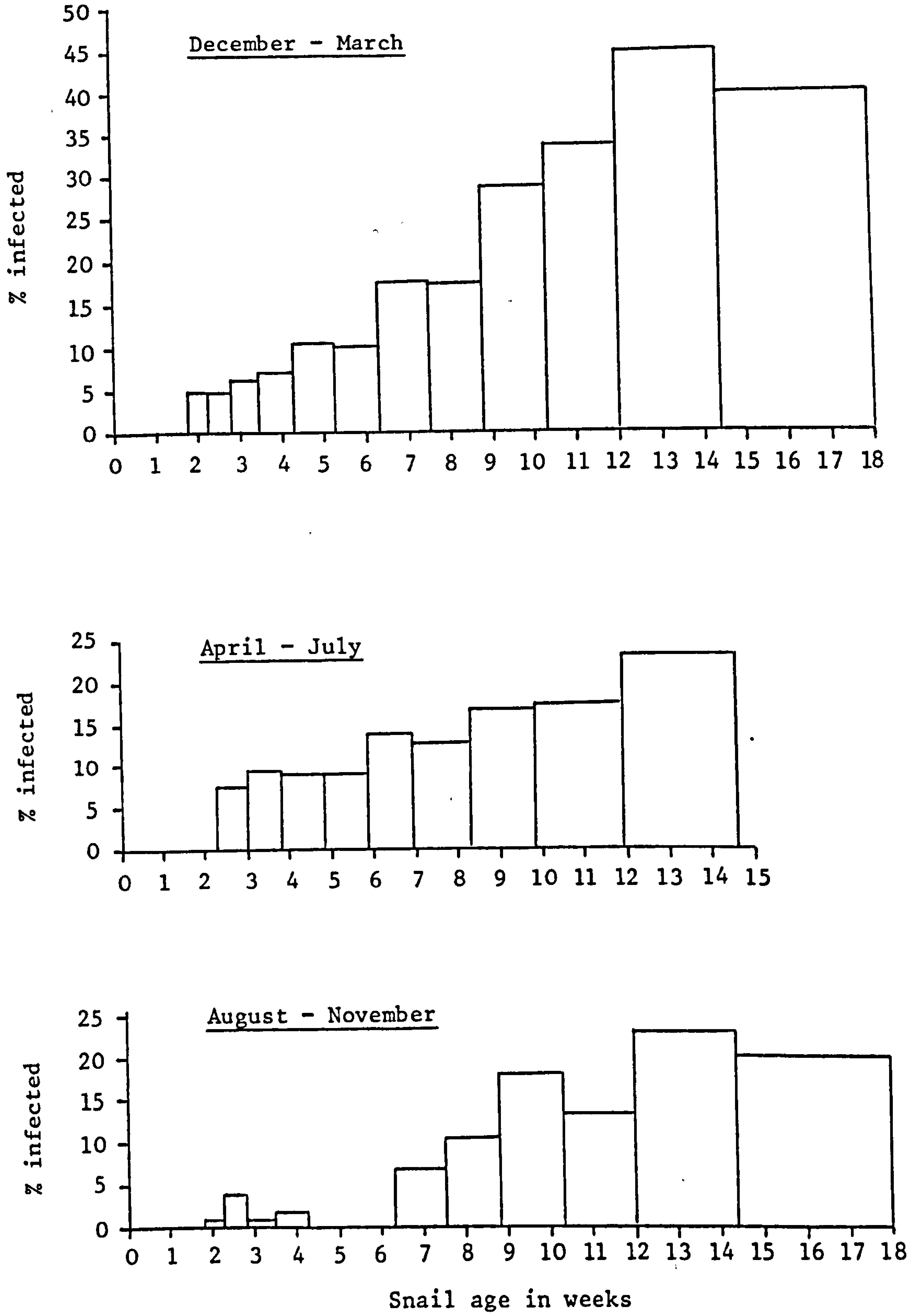


Fig. 24. Overall percentages of age-specific infection rates of patent S. haematobium cercariae in B. rohlfsi, by season.

undisturbed in the lake in wire-mesh cages. But these cages were kept suspended in shady locations at a constant depth of about 0.5 m within patches of vegetation. The maximum water temperature in this location would not have exceeded 32° C. In the main "snail zone" of Volta-Lake WCPs (0 - 10 m from shore), maximum water temperature often exceeded 36° C for short periods (unpublished data). Gordon, Davey, and Peaston (1934), Foster (1964), and Pflüger (1980) showed experimentally that the minimum prepatency period of S. mansoni development in B. pfeifferi could be as short as 16 days if mean water temperature was as high as 32 - 33° C.

In Figure 25, overall age-specific infection rates are presented for results from the sampled WCP at Bridgeanu-Ahenkro. Between 1978 - 1980, more infected snails were found in that WCP than in any other sampled location around the lake.

The shape of the histograms for Bridgeanu-Ahenkro is revealling. First, it implies that the snails were exposed to an extremely high force of infection. The WCP must have been constantly full of S. haematobium miracidia because even the smallest snails collected (3 weeks of age or so) had an infection rate of 37.5%. Second, the rapid flattening-out of the histograms after 3 weeks of snail age implies that the patent infections caused very rapid snail mortality.

In April 1979, 112 B. rohlfsi were collected from the same WCP, and 60 had patent S. haematobium infections. The next month, 32 B. rohlfsi were found - 29 with patent cercariae and 4 with prepatent cercariae of S. haematobium. No snail egg clutches were seen in the May collection. For the following 6 months, no more B. rohlfsi were found in the WCP despite continued sampling. This was a case of S. haematobium killing-off an entire snail population. Like elsewhere, snails with mature cercariae at Bridgeanu-Ahenkro were easily identifiable by their greenish colour. This indicated critical morbidity.

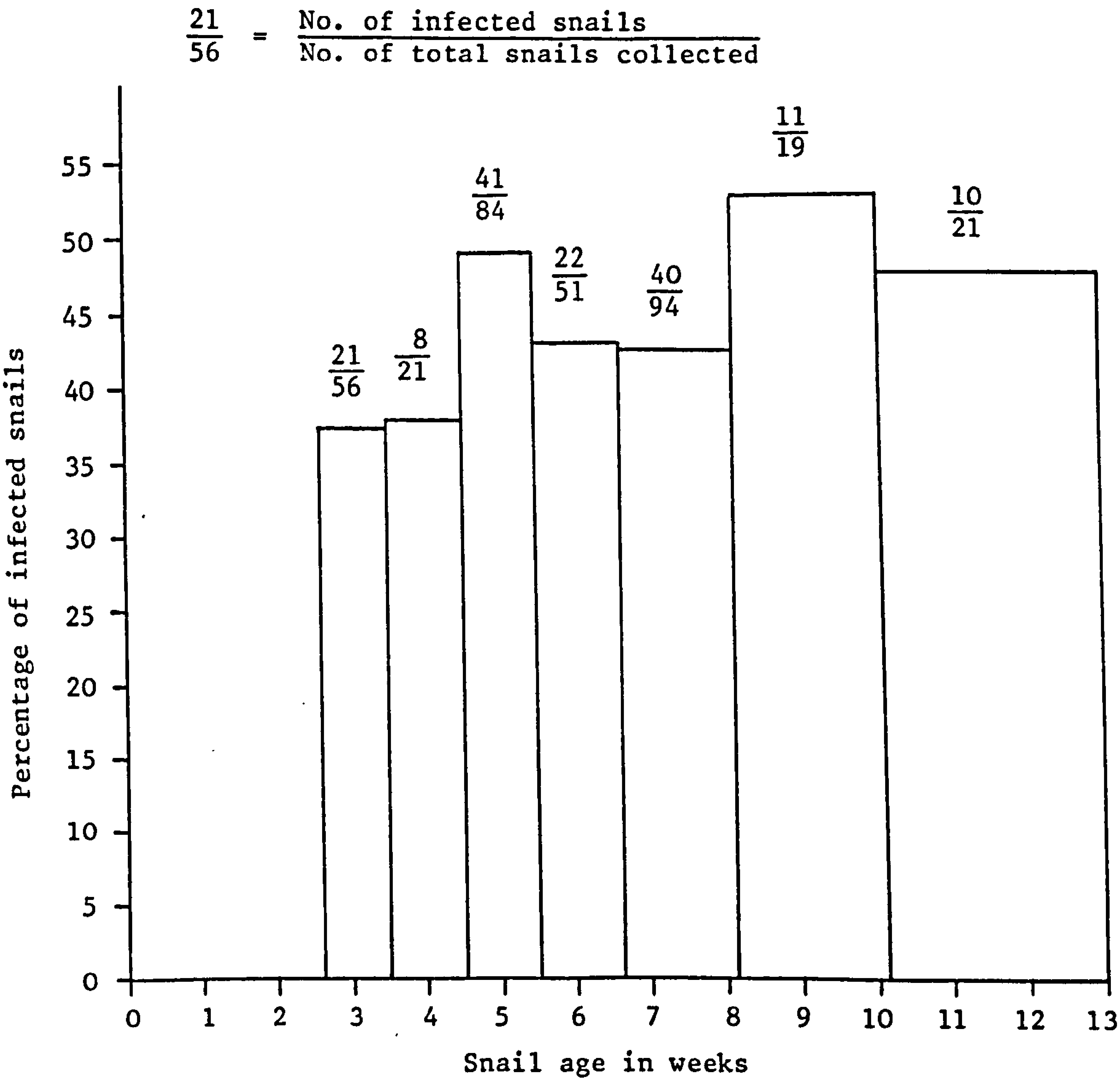


Figure 25. Age-specific histograms showing percentage of patent S. haematobium infections in B. rohlfsi, from sampling results at Bridgeanu-Ahenkro.

6.8 MATHEMATICAL MODEL TO DESCRIBE TRANSMISSION OF *S. HAEMATOBIUM* TO *B. ROHLFSI*

6.8.1 Introduction

In recent years, much emphasis has been placed on developing models to quantify transmission of schistosomiasis (notably, Hairston, 1962; MacDonald, 1965; Goffman and Warren, 1970; Nåsell and Hirsh, 1971; and Rosenfield, Smith, and Wohman, 1977). But few studies have devoted attention to quantifying parameters relevant in transmission of schistosomiasis to snails (Sturrock and Webbe, 1971; Pflüger, 1976).

The analysis by Pflüger (ibid) was from a field study in Madagascar involving *S. mansoni* in *B. pfeifferi* from irrigation ditches. As in the present study, infection rates in the Madagascar snails correlated closely with increasing snail age, which could be described by a linear regression line. But this finding could not explain much about the rates at which snails were gaining and losing infections.

The latter 2 forces were quantified for various snail-intermediate hosts by Sturrock and Webbe (1971) using a 2-stage catalytic model. However, the model was developed by Muench (1959) to describe the transmission dynamics of infection in humans for an age span where mortality would be negligible. This is not the case in snails where natural mortality, and mortality caused by a schistosome infection are high. While Sturrock, Cohen, and Webbe (1975) were able to incorporate data on natural and selective mortality in a 2-stage catalytic model for St. Lucian *B. glabrata*, which modified slightly the original, predicted force of infection and force of loss of infection, it seemed to put strain on the basic concept of the model and was applicable only if snail death rates followed a $\log_e$ normal curve.

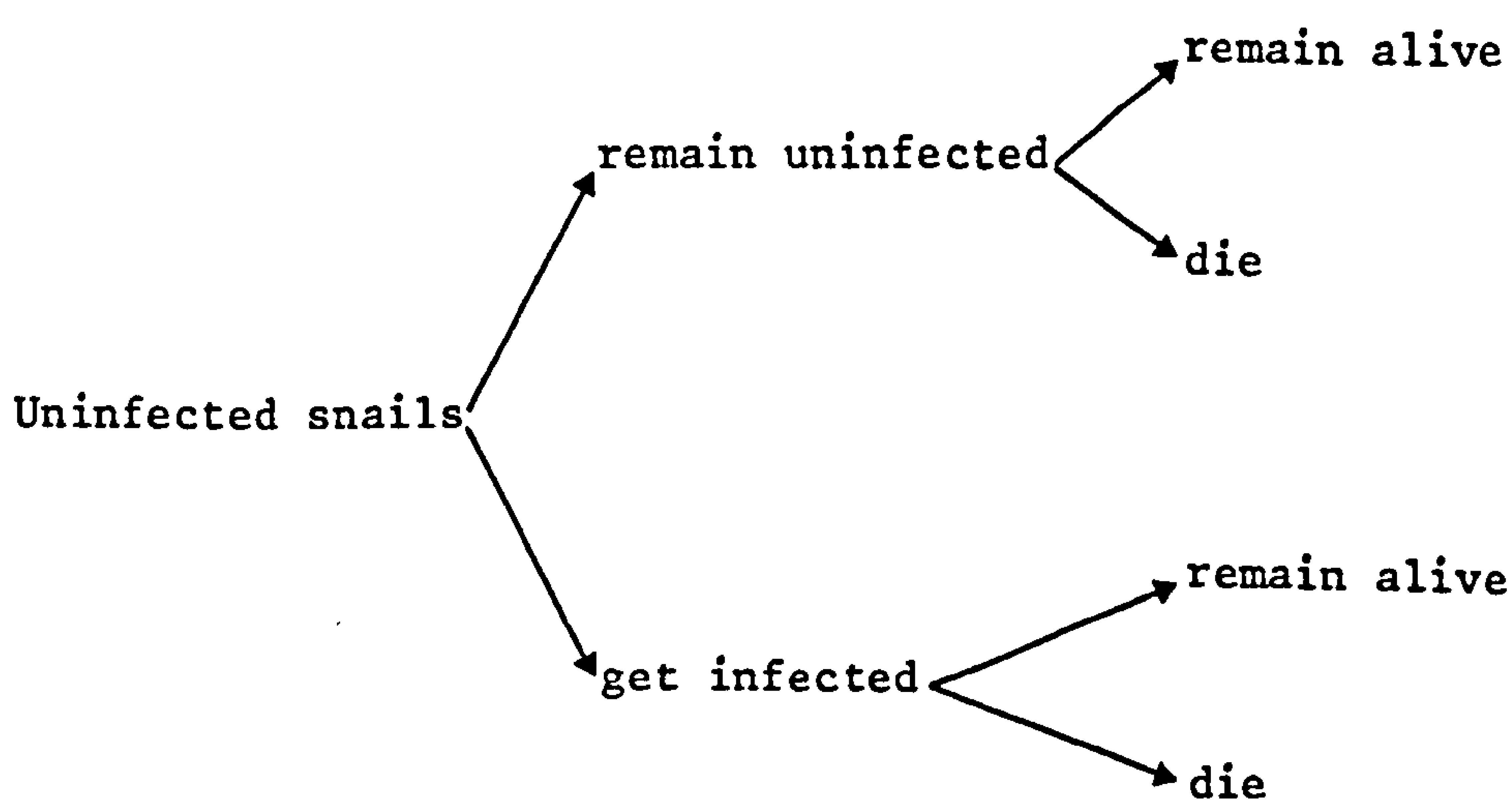
Data from other studies have shown that natural snail death rates do not always occur exponentially (Shiff, 1964; Chu, Massoud, and Arfaa, unpublished data; this thesis, to name a few).

From the field data gathered by the author on age-specific infection rates of *S. haematobium* in *B. rohlfsi*, it has been possible to develop a new mathematical model to describe the dynamics of transmission occurring in Volta-Lake *B. rohlfsi*.

The model considers 3 forces which together affect B. rohlfsi from the time specimens hatch until they die: (1) the force of infection, (2) the force of natural snail mortality, and (3) the force of mortality caused by patent S. haematobium cercariae.

The model is simple and logical, and should apply to any species of snail which is a natural host to any schistosome species.

For the present application, the model is based on a hypothetical cohort of B. rohlfsi, from the first day of hatching to a time when over 95% of the snails would be expected to be dead. With each t + 1 increment of time, the following mutually exclusive events could occur to the cohort.



The only detailed information needed to feed into the model is life table information on natural snail death rates. The other 2 forces can be predicted in achieving a reasonable fit of the model to observed age-specific infection rates.

As in all mathematical models, errors of data input and false assumptions are inherent in the system. For the present application, however, the chance of error has been minimized by the large numbers of total and infected snails collected (thereby reducing sampling error), from excellent agreement on natural snail mortality from "outdoor" laboratory studies conducted at 2 different locations near the Volta Lake in 2 different seasons, and good agreement on snail growth rates between lab and field analyses.

In the present application of the model, it is hoped that an accurate estimate can be made on the rate per week at which B. rohlfsi were getting infected, dying naturally, and dying from the infection.

It is also hoped that the model can have practical value, perhaps in control programmes against schistosomiasis, by being able to quickly assess the efficacy of intervention measures aimed at reducing miracidial contamination.

6.8.2 Materials and methods: Derivation of model

The end product of the model is the quantification of the following parameters:

(1) U(t) = number of uninfected snails

(2) I(t) = number of infected snails

(3) p(t) = proportion of infected snails

$$= \frac{I(t)}{I(t) + U(t)}$$

In the model, each unit of t is defined as 7 days. For every t increase to t + 1, U(t) changes to U(t + 1) as follows:

$$U(t+1) = U(t) \times P(\text{alive, uninfected}) \times P(\text{not infected})$$

where P(alive, uninfected) is the probability of a snail being alive, given that it is uninfected, and P(not infected) is the probability of a snail not being infected.

P(not infected) is derived by assuming that from the time of hatching until old age, a snail would be expected to be exposed to a constant force of infection, "a". As in catalytic models for human infections, it is assumed that

$$P(\text{not infected}) = e^{-a}$$

P(alive, uninfected) can be termed the probability of the force of mortality in uninfected snails. It is derived from the observed survivorship (l_x) of snails from life table information.

In the present case, l_x values were based on snails raised in lake water without mud in the outdoor laboratory at Agbenoxoe, from January to May 1980. (Survivorship among the snails raised in lake water plus mud was so good that it was probably not as reflective of normal survival of B. rohlfsi in the Volta Lake.) The observed survivorship of the "lake water" snails agreed closely with a similar experiment conducted by the author at the Anyaboni laboratory between September and January, 1975 - 1976. Both survival curves closely followed a "normal" probability function, from which the predicted survivorship values (l) used in the model were determined for each weekly value of t.

t	l	t	l
0	1.000	11	.624
1	.971	12	.562
2	.959	13	.500
3	.943	14	.438
4	.923	15	.376
5	.898	16	.318
6	.866	17	.264
7	.829	18	.214
8	.786	19	.160
9	.736	20	.122
10	.682	21	.079

For each increase of t to t + 1, $P(\text{alive, uninfected}) = \frac{l(t+1)}{l(t)}$.

Thus, $U(t+1) = U(t) \times e^{-a} \times \frac{l(t+1)}{l(t)}$.

The next step is to calculate I(t). When t increases to t + 1,

$$I(t+1) = I(t) \times P(\text{alive, infected}) + U(t) \times P(\text{alive, uninfected}) \times P(\text{infected})$$

where P(alive, infected) is the probability that a snail will be alive, given that it is infected, P(infected) is the probability of a snail getting infected, and U(t) x P(alive, uninfected) was defined above.

Since P(uninfected) = e^{-a} , P(infected) = $1-e^{-a}$

The remaining probability to consider is P(alive, infected). This is derived by first assuming that the force of mortality in snails with patent infections is greater than the force of mortality in uninfected snails by a constant multiple, λ. Assuming that within each weekly interval of t, the force of snail mortality, defined as b, is constant,

$$P(\text{alive over 1 week, uninfected}) = e^{-b}$$

$$P(\text{alive over 1 week, infected}) = e^{-\lambda b}$$

For each weekly change of t, where the observed death rates in uninfected snails follows a normal curve,

$P(\text{alive, infected}) = \{l(t+1)/l(t)\}^{\lambda}$, or, substituting y for $l(t+1)/l(t)$,

$$P(\text{alive, infected}) = y^{\lambda}.$$

Notable laboratory studies on schistosomiasis in snails (see discussion) have shown that λ is greater in younger snails than in older snails. *This was implied in the present study from the shape of the age-specific infection rates in Figure 24.*

To enable the model to give a good fit to the observed results in the present application, it is necessary, and seemingly justifiable, therefore, to multiply λ by a suitable constant for B. rohlfsi that were 2 to 5 weeks of age. Therefore, in the present case, λ is dependent on t and,

$$P(\text{alive, infected}) = y^{\lambda(t)}$$

In summary,

$$I(t+1) = I(t) \times y^{\lambda(t)} + \{U(t) \times y \times (1-e^{-a})\}$$

The final step in the model is to programme all of the relevant information for computer analysis. For the present application, the programme is written in BASIC and is reproduced in full in Appendix B.

6.8.3 Results

The model was applied to the overall results of age-specific infection rates plus those for December to March and August to November. It was felt that the model would not be applicable to the total results for the April to July season nor those from the main WCP at Bridgeanu-Ahenkro, because of excessive and variable snail mortality in the latter 2 situations.

Detailed results of U(t), I(t), and p(t) predictions are given in Table 34 for the presented applications. The predicted values of p(t) are fitted to the observed curves in Figure 26.

In Figure 26, very good fits were achieved by the model in all 3 applications. Ninety-five percent confidence intervals of observed infection rates were constructed for the overall results and those for the high transmission season. (They were not drawn for the low transmission season because they would have been exceptionally large due to the low numbers of snails collected.)

The predicted force of infection per week was .061 for the high transmission season, .05 overall, and .03 for the low transmission season. These values can be interpreted as the "instantaneous incidence rates" (Farooq and Hairston, 1966), or, better still, as the predicted minimum number of "effective snail/miracidium contacts" per week (Sturrock and Webbe, 1971). In the present application, this amounted to 6, 5, and 3 effective miracidial contacts per every 100 *B. rohlfsi* per week respectively.

Overall, and in the high transmission season, the predicted force of mortality in infected snails was 1.75 times higher than each weekly force of mortality in uninfected snails for specimens older than 5 weeks; for snails 2 - 5 weeks old, the λ factor was 17.5 times higher. In the low transmission season, λ was 1.8 times higher for the older snail group, and 36 times higher in the younger snail group. (The latter 2 values should be viewed with caution due to the low probability of finding infected, young snails in this season and the low numbers of total snails collected.)

Overall					High transmission season					Low transmission season				
t	p	I	U	I+U	t	p	I	U	I+U	t	p	I	U	I+U
0	0	0	100	100	0	0	0	100	100	0	0	0	100	100
1	0	0	97.1	97.1	1	0	0	97.1	97.1	1	0	0	97.1	97.1
2	0	0	95.9	95.9	2	0	0	95.9	95.9	2	0	0	95.9	95.9
3	.044	4.1	89.7	93.8	3	.053	5.0	88.7	93.7	3	.023	2.2	91.5	93.7
4	.072	6.5	83.5	90.0	4	.088	7.8	81.7	89.5	4	.033	3.0	86.9	89.9
5	.086	7.3	77.3	84.6	5	.105	8.7	74.8	83.5	5	.033	2.8	82.1	84.9
6	.128	10.4	70.9	81.3	6	.155	12.4	67.8	80.2	6	.061	4.9	76.8	81.7
7	.167	12.9	64.6	77.5	7	.200	15.3	61.1	76.4	7	.086	6.7	71.4	78.1
8	.201	14.7	58.2	72.9	8	.241	17.3	54.5	71.8	8	.109	8.1	65.6	73.7
9	.233	15.7	51.9	67.6	9	.277	18.4	48.0	66.4	9	.130	8.9	59.7	68.6
10	.260	16.0	45.7	61.7	10	.308	18.6	41.9	60.5	10	.149	9.4	53.6	63.0
11	.283	15.7	39.8	55.5	11	.335	18.2	36.0	54.2	11	.165	9.4	47.6	57.0
12	.302	14.8	34.1	48.9	12	.357	17.0	30.5	47.5	12	.178	9.0	41.6	50.6
13	.318	13.5	28.8	42.3	13	.376	15.4	25.6	40.9	13	.189	8.4	35.9	44.3
14	.330	11.9	24.0	35.9	14	.390	13.5	21.1	34.6	14	.196	7.5	30.6	38.1
15	.338	10.0	19.6	29.6	15	.400	11.3	17.0	28.3	15	.201	6.4	25.5	32.0
16	.343	8.2	15.8	24.0	16	.406	9.3	13.5	22.8	16	.204	5.3	20.9	26.2
17	.345	6.6	12.5	19.1	17	.409	7.3	10.6	17.9	17	.204	4.3	16.8	21.1
18	.342	5.0	9.6	14.6	18	.407	5.5	8.1	13.6	18	.201	3.3	13.2	16.5
19	.327	3.3	6.8	10.1	19	.392	3.7	5.7	9.3	19	.189	2.2	9.6	11.8
20	.317	2.3	5.0	7.3	20	.381	2.5	4.1	6.6	20	.181	1.6	7.1	8.7
21	.284	1.2	3.1	4.3	21	.345	1.3	2.5	3.8	21	.157	0.8	4.5	5.3

Table 34. Predicted values of the proportion of infected snails (p), number of infected snails (I), and number of uninfected snails (U) during each week (t) of most of the predicted lifespan of respective cohorts of 100 initial B. rohlfsi in the Volta Lake, overall, in the high transmission season, and in the low transmission season.

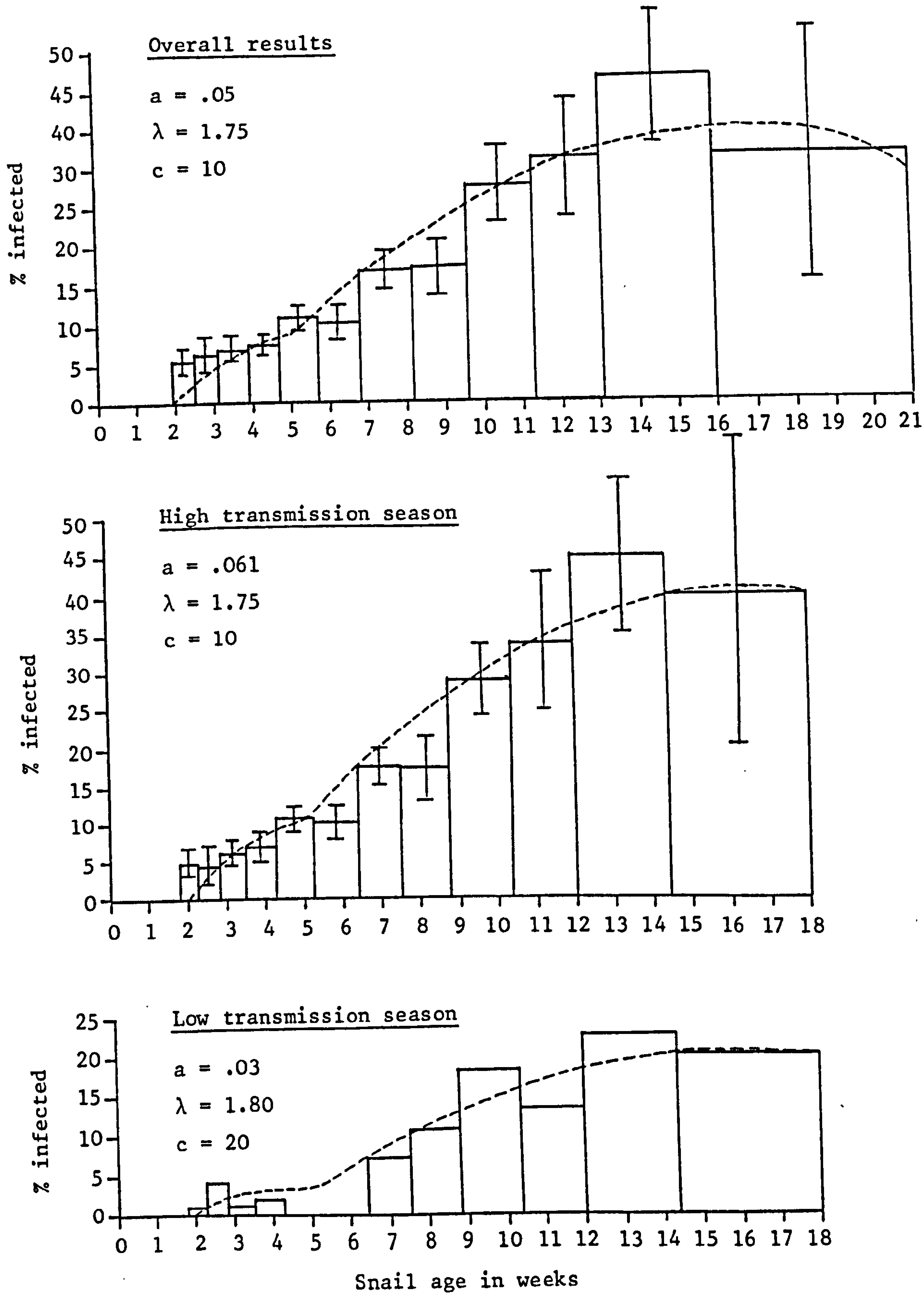


Fig. 26. Fitted curves from the model to observed histograms of age-specific infection rates. a = force of infection per week; λ = ratio of the probability of mortality per week between infected and uninfected snails; c = constant multiplied to λ for snails 2 - 5 weeks old; I = confidence interval.

In all 3 applications, the model under-estimated infection rates in snails that were assumed to be 2 - 3 weeks old. As stated, infected snails in this age span were probably older than indicated, most likely having had their growth stunted by *S. haematobium*.

6.8.4 Discussion

In the present application, the model indicated that the force of infection in the high transmission season was twice as high as it was in the low transmission season.

The main reason for this seasonal variation was probably due to seasonal variation in human water contact. Evidence will be presented later to show that in one village - Agbenoxoe - frequency and duration of water contact were lowest in November and then increased steadily until the end of the following dry season in April. Human water contact dropped-off again in May and June following the onset of the rainy season.

Although water contact is probably reduced in most lakeside villages between August and November, there is no reason to assume that the force of infection in this season is not constant. From the age-specific results presented, youngest snails were getting infected, and the failure to find infected snails 5 and 6 weeks of age was to be expected in light of the low overall snail density in this season. WCPs are smallest in area between September and November, and contamination by humans would have to be greatly reduced to interrupt transmission of miracidia to snails.

The high predicted λ factor for young snails in the low transmission season could be explained by the fact that WCPs often contain stagnant, polluted water, which is not favoured by *B. rohlfsi*. The combination of the poor environment and *S. haematobium* infection could be more detrimental to younger infected snails than older specimens.

The general assumption of significantly higher mortality in youngest infected *B. rohlfsi* vs. "middle-aged" infected *B. rohlfsi* is supported by experimental evidence involving other intermediate snail hosts. In Iran, Chu, Massoud, and Sabbaghian (1966) infected equally 2 batches of *B. truncatus* to *S. haematobium* miracidia from humans. At exposure, one snail batch was 2 - 6 days old, the other, 19 - 26 days old. Fifty days after exposure, 34.1% of the younger snails died compared to only 1.1% of the older snails. In St. Lucia, Sturrock and Sturrock (1970) found that *B. glabrata* infected at 2 days of age with *S. mansoni* miracidia died at a much faster rate in the following 8 weeks than *B. glabrata* infected at 6, 12, or 24 days of age.

If the assumption of a differential mortality rate between young and middle-aged, infected *B. rohlfsi* is true, the greater tolerance of the older snails to the killing effect of patent cercariae probably does not appear in one "quantum leap" as is programmed in the model. However, at present a suitable function has not been found, and for the time being, the multiplication of λ by a constant for 2 - 5 week-old snails will have to stand.

It would be desirable for the present transmission model to be tested in endemic areas of schistosomiasis other than just the Volta Lake. Key information needed to verify the accuracy of the predicted 3 forces would be *field data* collected fortnightly: infection rates, snail growth rates, age-specific mortality in uninfected snails, and age-specific mortality in infected snails.

CHAPTER 7

ECOLOGICAL AND EPIDEMIOLOGICAL FEATURES OF THE SAMPLED VILLAGES AND SPECIFIC FINDINGS ON CERCARIAL TRANSMISSION POTENTIAL IN THEM

7.1 INTRODUCTION

The purpose of this chapter is to present summary results of snail sampling in each of the 39 villages. This is necessary not only to highlight the variation in results between villages and lake sections, but also to list basic epidemiological and ecological features of the respective villages, hopefully, to benefit others planning future research on the disease at the Volta Lake.

7.2 DESCRIPTION OF SAMPLED VILLAGES IN AFRAM BRANCH

The location of all 9 sampled villages in the Afram branch can be seen in Map 8. They represented about 29% of all lakeside villages on the south shore between the northwestern limit of the WHO study area and a few km east of the eastern limit of the WHO comparison area. One of the 9 villages, Bekoe B, was actually a study unit in the comparison area.

Nahrpawnya was at a shallow cove full of partially submerged tree skeletons. The sampled WCPs were also the main WCPs for most of the residents of Dedeso, a VRA resettlement community, 2 km away, where about 3000 people lived. But after March 1979, one WCP became so polluted from rotting *Ceratophyllum* and blue-green algae that people stopped using the point. People positive for *S. haematobium* at Nahrpawnya were treated with metrifonate by the Ghana Ministry of Health in 1979 (after the author collected prevalence data). The chemotherapy did not affect the present snail sampling results because few *B. rohlfsi* were found - before or after treatment.

Sonukpo was located at a stream inlet a few km northeast of Dedeso. Positive children were treated with metrifonate in 1979, before a prevalence survey could be conducted. Again, this did not adversely affect snail sampling results. The number of infected snails collected actually increase after chemotherapy!

Dortopong was at a shallow, wide cove near the resettlement village of Amate and near a UNDP spray irrigation project.

Kpetinu was at a steep, narrow inlet of the lake which received the waters of the Asuboni River.

A few km west was the large fishing village of Asuboni. It was at a straight part of the shore where the lake was over 7 km wide and thus exposed to considerable wave action.

Kwahu Adawso was the largest of the 9 villages. It was the only ferry crossing point to the Afram Plains. The town was mainly composed of ferry workers from the Ghana Highways Department, indigenous Kwahu farmers and traders, and Ewe fisherfolk. One of the sampled WCPs was a few metres from the ferry landing, where many travellers had water contact. The other WCP was the main swimming point for school children. On-going epidemiological surveys for _S. haematobium_ , begun by WHO in 1976, were being maintained by the Ghana Ministry of Health.

Bekoe B was an important fishing and trading village.

The sampled WCPsat Asumjeri were along a wide, deep inlet, fringed with dense emergent weed growth and thick masses of _Ceratophyllum_. The main WCP was a few metres from a newly constructed water works pumping station, which was designed to serve major towns on the Kwahu escarpment.

The last sampled village, Dedekrom, was on the western side of the inlet, 3 km opposite Asumjeri, and could be reached only by canoe. The slope of the shore was so flat that a 100 - 200 m zone of emergent _Polygonum_ surrounded and obscured the WCP during most months.

Map 8

Sampled villages, important towns, roads, rivers streams, and the Kwahu Escarpment at or near the Afram branch of the Volta Lake.

Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	Prev. rate (%) of *S. haematobium*: 5-19 yrs.	WCP Location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants Dec. - Mar. yr. 1	Rooted plants Dec. - Mar. yr. 2	*Ceratophyllum* Dec. - Mar. yr. 1	*Ceratophyllum* Dec. - Mar. yr. 2	*Ceratophyllum* Apr. - Jul. yr. 1	*Ceratophyllum* Apr. - Jul. yr. 2
Nahrpawnya	122	Ewe, Ada	68.8	84.3	Semi-cove	2/3	2.6	1.2	2.5	1.2[a]	3.0	1.0[a]
Sonukpo	145[b]	Ewe	-[c]	-[c]	Stream inlet	2/3	2.2	3.0	2.5	3.0	2.8	2.0
Dortopong	94	Ewe	87.1	96.0	Semi-cove	1/1	0.5	1.0	2.0	0.2	2.0[a]	0
Kpetinu	71	Ewe	80.0	91.7	Stream inlet	1/1	0.5	0.5	2.0	1.2	2.0[a]	0
Asuboni	450[b]	Ewe, Ada	-	74.6	Open shore	2/4	0.2	0.2	0	0	1.0	0
Kwahu Adawso	757[d]	Ewe, Ada	68.6[d]	-	Stream inlet	2/8	1.6	1.8	2.5	0.8	1.8	0.5
Bekoe B	220[d]	Ewe	72.1[d]	88.8[d]	semi-cove	2/6	2.1	2.6	2.5	2.5	2.4[a]	1.4
Asumjeri	85	Ewe	66.1	85.2	Weedy shore	2/2	2.5	3.0	2.8	3.0	3.0	2.7
Dedekrom	76	Ewe	71.7	90.0	Weedy shore	1/1	2.2	3.0	2.5	2.7	3.0[a]	3.0

a = rotting *Ceratophyllum* causing water pollution; b = estimate; c = villagers treated with metrifonate in 1979; d = WHO data.

Table 35. Epidemiological and ecological features of sampled villages in Afram branch.

7.2.1 Explanation of snail sampling results (Tables 36 and 37)

With the exception of Sonukpo and Kwahu Adawso, total mean numbers of infected snails per WCP and total percentages of cercarial-infested WCPs were low in every Afram-branch village - less than 1.0 and 18% respectively. Except for the 2 Daka-branch villages, values of the above parameters for each December - March season were lower than in any other lake section surveyed in the same period.

However, the potential for transmission in each April - July season was relatively high - 28.3% and 26.3% of WCPs contained infected snails in this season in 1979 and 1980. The seasonal percentages were higher only in the Obosum branch.

At Nahrpawnya (1st yr.), Bekoe B (WCP 2), Kwahu Adawso (WCP 2), Asumjeri, and Dedekrom, populations of B. rohlfsi could not expand between December and March periods because emergent vegetation in and around WCPs was too thick to allow mixing with offshore water. The water was stagnant and often polluted.

WCPs were more open and less polluted between April and July each year. However, decaying Ceratophyllum in this season caused periodic pollution in WCPs at Nahrpawnya, Dortopong, Kpetinu, Bekoe B (WCP 2), and Dedekrom.

The results in Tables 36 and 37, indicating sporadic transmission between December and March and more intense transmission between April and July, are similar to snail sampling results from the WHO comparison area when work was conducted there in 1977 and 1978 (unpublished data).

It is not clear whether the high human prevalence rates and egg counts recorded in the present study were a reflection of the type of transmission observed from snail sampling, or that levels of infection have remained high in the villages because of intense transmission that seems to have occurred in the Afram branch before 1977 (Jones, 1973; M.A. Odei, personal communication).

Table 36. Mean number of infected *B. rohlfsi* over mean number of total *B. rohlfsi* collected per WCP by season in Afram-branch villages, 1978-80.

Village		December - March yr. 1	December - March yr. 2	April - July yr. 1	April - July yr. 2	Aug.-Nov. yr. 1+2	Total
Nahrpawnya		0.5/9.8	0/1.5	0/17.3	0	0/2.3	0.1/6.1
Sonukpo	1)	0/1.0	2.0/30.2	0.3/15.3	5.0/38.7	0	1.4/16.9
	2)	0/3.2	0/38.0	0.7/11.7	2.5/31.0	0/2.0	0.5/13.7
Dortopong		1.5/8.8	0/1.2	0	0	0	0.4/2.4
Kpetinu		0.5/11.0	0/2.5	1.2/15.0	0	0/0.5	0.4/5.8
Asuboni	1)	0	0	0/7.0	0	0/0.2	0/1.4
	2)	0/2.0	0	1.5/13.5	0	0/0.5	0.3/3.2
K. Adawso	1)	0	0	3.2/28.8	2.5/14.0	0	1.4/10.1
	2)	4.8/24.8	0/13.0	1.8/11.5	0/6.0	2.0/6.8	1.4/13.5
Bekoe B	1)	0/3.5	1.0/23.8	0.8/27.0	0/2.5	0.4/10.0	0.4/13.7
	2)	0/6.2	0.5/1.5	0/11.5	0	0/1.0	0.2/4.0
Asumjeri	1)	1.5/17.2	0/1.8	0/8.2	3.0/76.3	0/4.2	0.8/18.8
	2)	0/1.0	0	0/5.2	-	0	0/1.8
Dedekrom		0/8.0	0	0/4.5	0/27.3	0	0/6.6
Overall mean values		0.6/6.4	0.4/7.7	0.8/13.1	0.9/14.2	0.2/2.0	0.6/8.5

Table 37. Fraction of cercarial-infested WCPs by season in Afram-branch villages, 1978 - 1980.

	December - March		April - July		Aug.-Nov.		
	yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	Total	%
Nahrpawnya	0/8	0/4	0/3	0/3	0/3	0/21	0
Sonukpo	0/8	3/6	2/5	5/5	0/6	10/30	33.3
Dortopong	2/4	0/4	0/3	0/3	0/3	2/17	11.8
Kpetinu	1/8	0/4	2/4	0/3	0/5	3/24	12.5
Asuboni	0/8	0/8	2/8	0/6	0/10	2/40	5.0
K. Adawso	3/6	1/8	6/10	3/6	1/8	14/38	36.8
Bekoe B	0/8	3/8	3/8	0/6	1/10	7/40	17.5
Asumjeri	1/8	0/6	0/8	2/3	0/10	3/35	8.6
Dedekrom	0/4	0/4	0/4	0/3	0/5	0/20	0
Total	7/62	7/52	15/53	10/38	2/60	41/265	
%	11.3	13.5	28.3	26.3	3.3	15.8	

7.3 DESCRIPTION OF VILLAGES IN THE OBOSUM BRANCH

This was the most difficult part of the lake to reach. By road, vehicles had to cross the Afram branch on the Kwahu Adawso Ferry and then traverse about 100 km of poor roads across the Afram Plains. The only village at the Obosum branch which could be reached by road was Bridgeanu-Ahenkro.

The sampled villages represented 5 out of about 26 lakeside villages in the entire branch and 5 out of 9 total villages on each bank from Bridgeanu-Ahenkro to Sodzi Kope (Map 9). Data from the sampled villages were probably representative of the entire branch.

The north and south shores were rocky and steep, full of inlets and coves which protected WCPs from strong wind and wave action. The entire area was woody, and projecting tree skeletons filled much of the littoral and limnetic zones. Fish, birds, and snakes were numerous. On one sampling occasion, a crocodile, about 4 m long, was observed less than 100 m from the main WCP at Ntonaboma. Despite the reptiles, water contact was intense in all sampled villages, especially swimming and playing by children.

Ceratophyllum seems to have invaded the Obosum branch after 1973. It was never reported in ecological surveys by Paperna, Pierce (weed survey), Odei, or Jones, in their travels to this branch between 1968 and 1973.

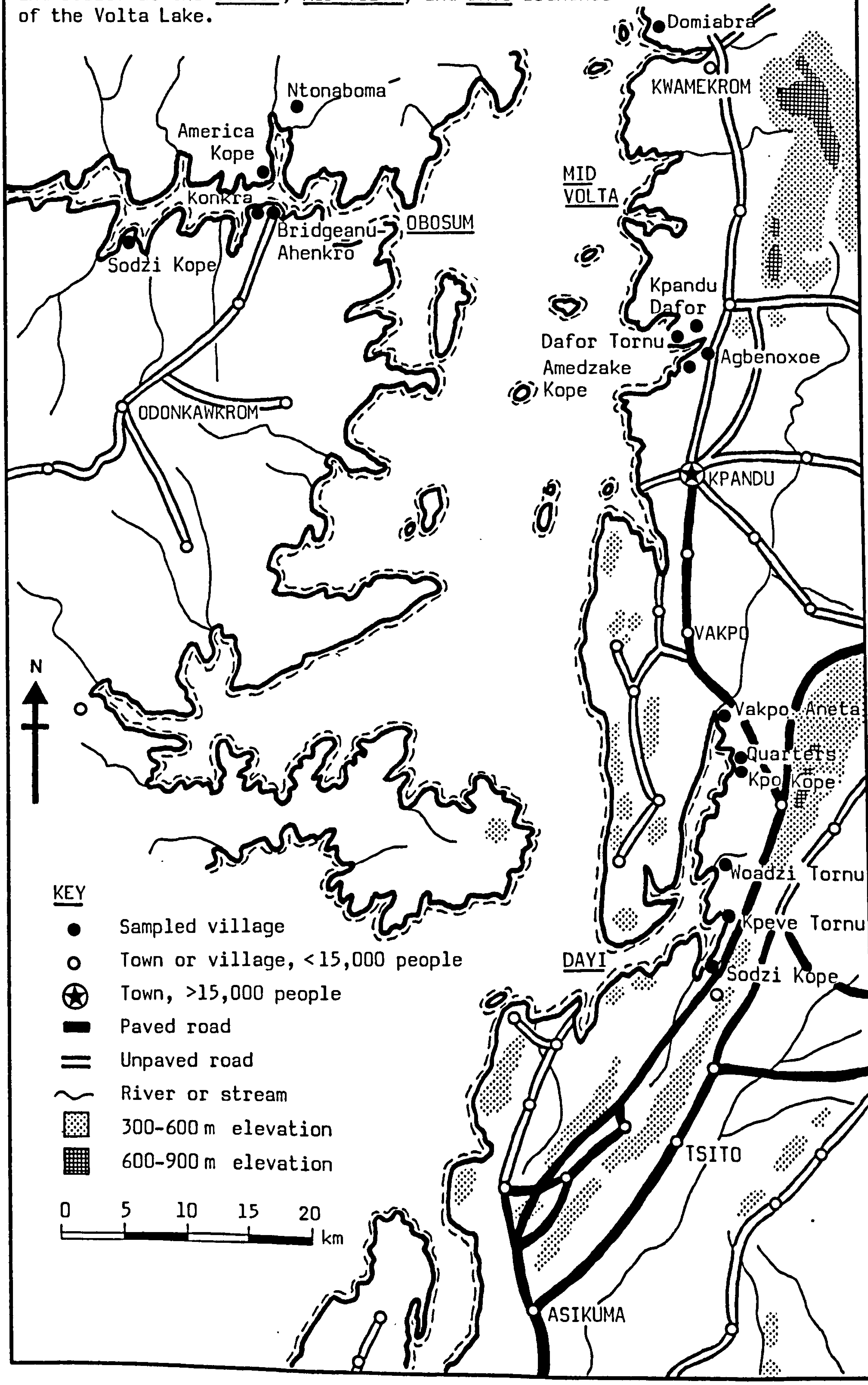
During the present period of sampling, Ceratophyllum was widespread at Bridgeanu-Ahenkro (1979), Konkra, Ntonaboma, and Sodzi Kope. However, due to the rocky and steep shore, growth of emergent vegetation was generally light throughout the branch.

Occasional B. globosus specimens were found at Sodzi Kope alongside B. rohlfsi. Despite the fear that the former snail might spread to other villages in the branch, it was not found in any other Obosum-branch village, and none of the specimens was infected with S. haematobium. Paperna (unpublished report) and Jones (1973) only found B. globosus in the lake at this branch (some infected with S. haematobium).

All of the sampled villages were fishing and farming communities, and Ntonaboma was a large VRA resettlement village. Features of the 5 villages are summarized in Table 38.

Map 9

Sampled villages, important towns, roads, rivers, streams, and relief at the OBOSUM, MID VOLTA, and DAYI branches of the Volta Lake.



Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	Prev. rate (%) of *S. haematobium*: 5-19 yrs.	WCP location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants, Dec. - Mar., yr. 1	Rooted plants, Dec. - Mar., yr.2	Ceratophyllum, Dec. - Mar., yr. 1	Ceratophyllum, Dec. - Mar., yr. 2	Ceratophyllum, Apr. - Jul., yr. 1	Ceratophyllum, Apr. - Jul., yr. 2
Bridgeanu-A.	349	Kwahu	70.6	91.9	2 small coves	1/3	0	0.5	1.8	0.2	2.0	0.3
Ntonaboma[a]	1800[b]	Kwahu	-	94.7	Stream inlet	1/1	1.2	1.5	2.2	2.5	0.2	3.0
Konkra	74	Ewe, Ada	96.7	94.3	Small cove	1/2	0.5	1.5	1.0	0.8	2.5	0.7
Sodzi Kope	183	Ewe	87.6	93.5	Stream inlet	2/3	0.6	0.6	0.1	0	0	0.8
America Kope	25	Ewe	83.3	100.0[c]	Open shore	1/1	0.5	0.8	0	0	0	0

a = VRA resettlement village; b = estimate; c = < 20 people surveyed.

Table 38. Epidemiological and ecological features of sampled villages in Obosum branch.

Plate 30. Section of the Obosum branch showing characteristic steep banks.

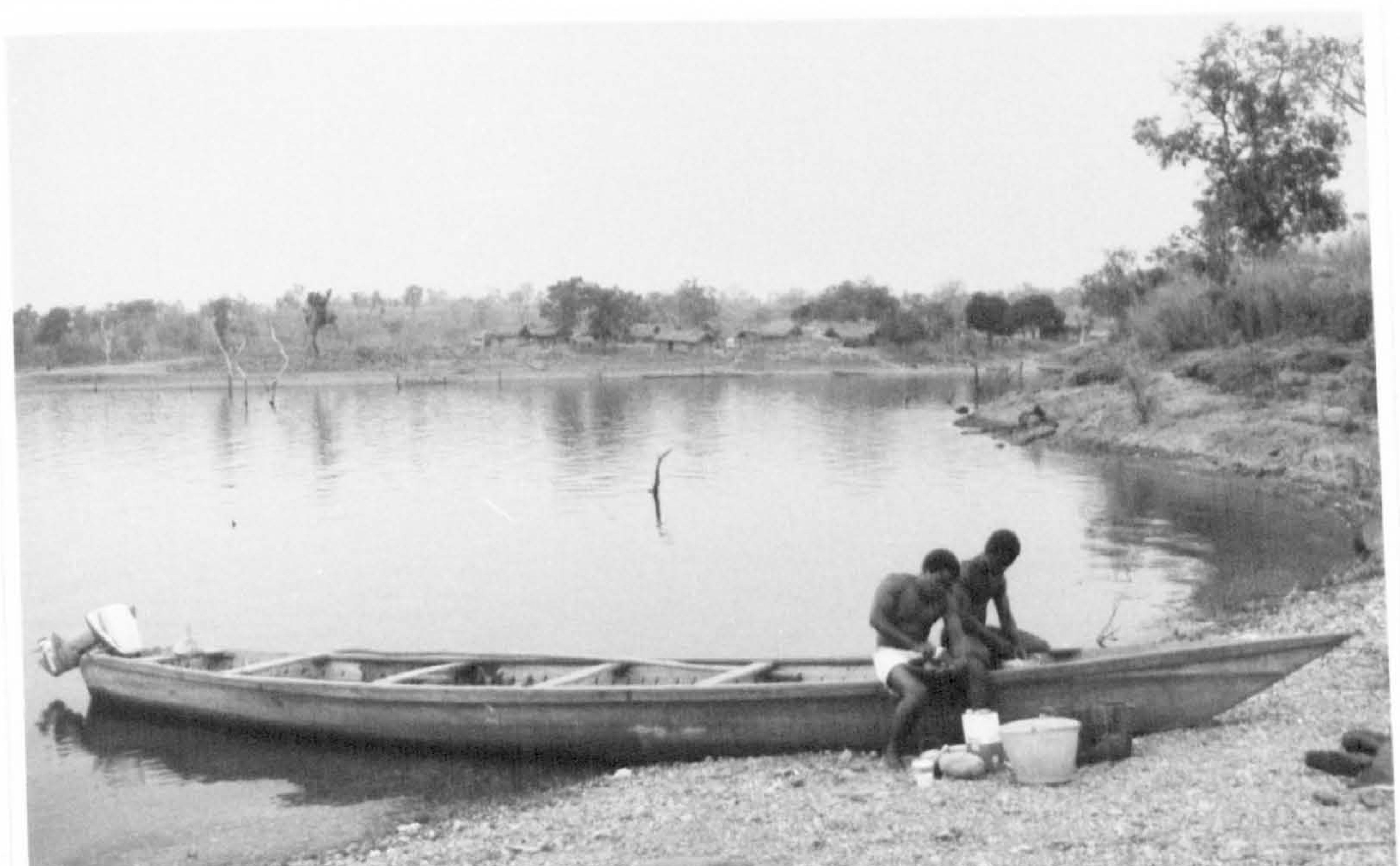


Plate 31. Camping near Bridgeanu-Ahenkro in the Obosum branch. Canoe was used to cross lake from Agbenoxoe and reach other Obosum villages.

Plate 30. Section of the Obosum branch showing characteristic steep banks.

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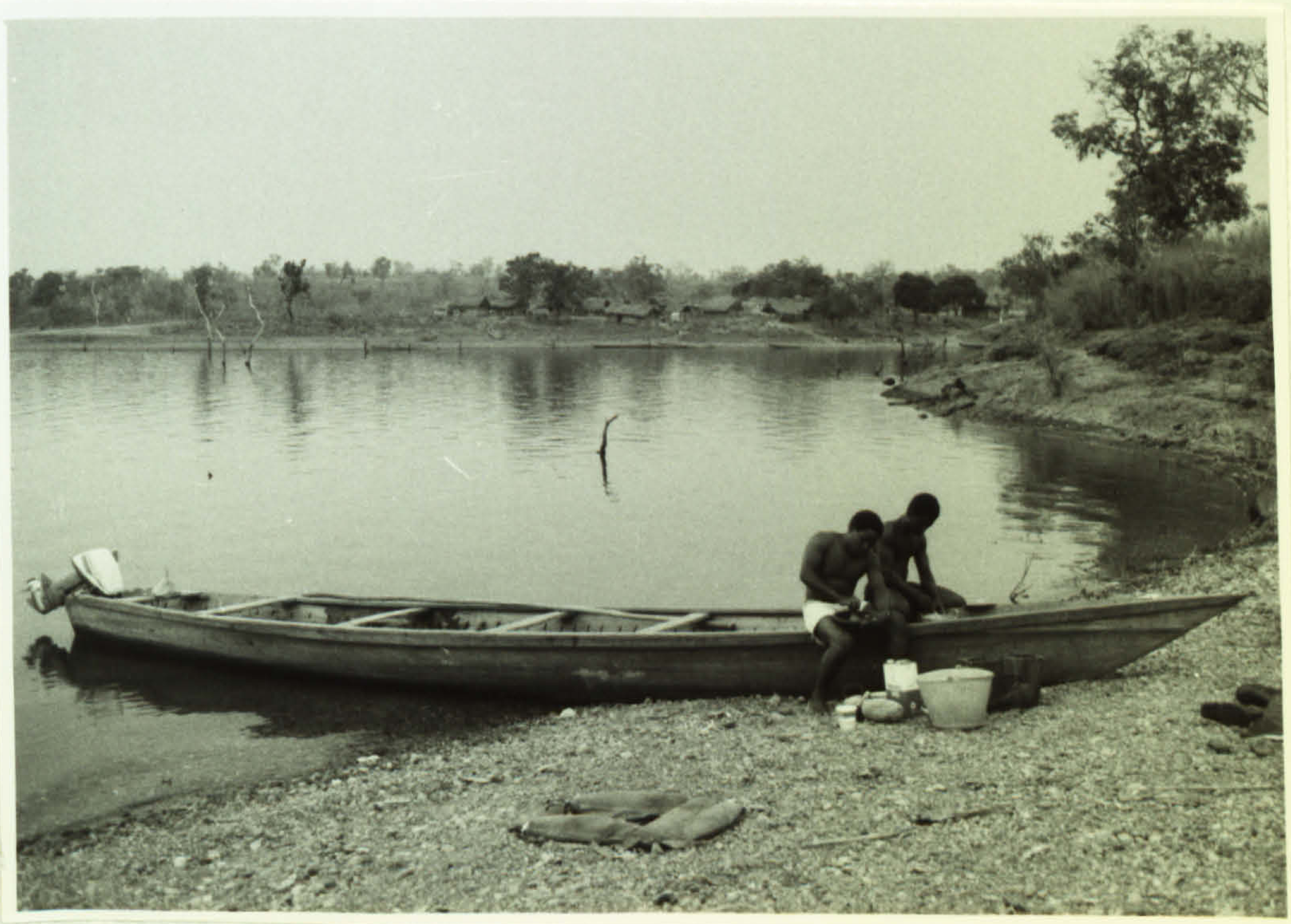


Plate 31. Camping near Bridgeanu-Ahenkro in the Obosum branch. Canoe was used to cross lake from Agbenoxoe and reach other Obosum villages.

7.3.1 Explanation of snail sampling results (Tables 39 and 40)

From the sampling results, the potential for *S. haematobium* infection in the Obosum branch was extremely high during each December to March season, and high during each April - July season. Transmission was low or absent only during the flood period. The total mean number of infected snails per WCP (4.3) and the overall percentage of cercarial-infested WCPs (54.0%) were the highest values ever recorded from long-term, area-wide sampling in the Volta Lake.

From raw data in the present study, 470 infected snails (39.2%) of all 1199 collected around the lake came from Bridgeanu-Ahenkro, Konkra, Ntonaboma, and Sodzi Kope.

Ecological conditions were favourable for high transmission in the above 4 villages. As in most Obosum-branch communities, the WCPs were either in tiny coves or narrow stream inlets and therefore protected against heavy wave action. Drawdown slopes were steep, and this kept horizontal movement of WCPs to a few metres per month. The rocky shore and light growth of emergent weeds kept water clean, encouraging frequent and prolongued human water contact. *Ceratophyllum* often grew in thick patches in the WCPs. At Bridgeanu-Ahenkro, Konkra, and Ntonaboma, 72.7% of all snails were collected from the weed.

During the first year, *Ceratophyllum* grew in moderate density at Bridgeanu-Ahenkro and Konkra. In 1980, it died-back extensively in the 2 villages, and this resulted in low snail collections during the final open beach season (April - June).

Ceratophyllum increased during the second year at Ntonaboma; it grew in a solid mass in the WCP from February to June, 1980.

Except for fragments of *Ceratophyllum* in the second main WCP at Sodzi Kope in January 1979, the weed remained absent from the littoral zone there until April 1980. Most snails at Sodzi Kope were collected in January - April 1980, from sticks, or directly from rocks, gravel, or sand at the water's edge.

Table 39. Mean number of infected B. rohlfsi over mean number of total B. rohlfsi collected per WCP by season in Obosum-branch villages, 1978-80.

Village		December - March yr. 1	December - March yr. 2	April - July yr. 1	April - July yr. 2	Aug.- Nov. yr. 1+2	Total
Bridgeanu-Ahenkro		9.0/27.0	6.5/21.8	22.2/37.2	1.8/1.3	0	8.1/18.3
Ntonaboma		11.5/59.8	8.5/63.8	0.2/9.2	2.0/34.3	0	4.8/35.2
Konkra		4.2/25.2	11.2/44.0	6.5/90.2	1.0/5.3	0/0.8	4.8/35.5
Sodzi Kope	1)	7.5/23.0	13.2/93.0	0	6.0/20.0	0.5/1.8	5.4/27.9
	2)	2.0/12.5	3.8/37.8	0	3.7/20.0	0	1.8/13.7
America Kope		1.5/12.5	1.8/48.5	0	0	0	0.7/13.6
Total		6.0/26.7	7.5/51.5	4.8/22.8	2.3/13.5	0.1/0.4	4.3/24.0

Table 40. Fraction of cercarial-infested WCPs by season in Obosum-branch villages, 1978 - 1980.

	December - March		April - July		Aug.-Nov.		
Village	yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	Total	%
Bridgeanu-Ahenkro	4/4	4/4	2/4	2/3	0/4	12/19	63.2
Ntonaboma	4/4	3/4	1/4	2/3	0/3	10/18	55.5
Konkra	4/4	4/4	4/4	2/3	0/4	14/19	73.7
Sodzi Kope	6/8	8/8	0/8	4/6	1/8	19/38	50.0
America Kope	2/3	3/4	0/4	0/3	0/3	5/17	29.4
Total	20/23	22/24	7/24	10/18	1/22	60/111	
%	87.0	91.7	29.2	55.6	4.5	54.0	

7.4 DESCRIPTION OF VILLAGES IN THE DAYI BRANCH

The 6 sampled villages were all on the east side of this narrow lake section and comprised about 50% of all villages on that shore, and about 30% of all villages in the branch (Map 9). The sampling results, therefore, can be viewed with confidence in regards to the range of transmission potential that existed in the entire branch between 1978 and 1980.

Epidemiological and ecological characteristics of the 6 villages are summarized in Table 41.

Sodzi Kope was a fishing village of about 100 people on the main Asikuma-Have-Hohoe road, 0.5 km from Todome where about 1500 people lived. The WCP for Sodzi Kope was at a sheltered stream inlet of the Dayi branch, less than 100 m from the main road, and used by many people from Todome as well as strangers. Some uninfected *B. globosus* were collected from the WCP in 1979 and 1980. Previously, the snail had never been reported in the lake outside of the Obosum branch and for one brief occasion, in the Pawmpawm branch in 1975, during the WHO project.

Kpeve Tornu was located near the Kpeve water works. The shore was gravelly and exposed to wind and waves.

Woadzi Tornu was at a wide cove and was composed of indigenous Ewe farmers and a non-indigenous Ewe faith healer who attracted visitors from all over southern Ghana and parts of Togo.

Kpo Kope and Quarters were 2 small fishing villages of Ewe squatters, located about 300 m apart at a shallow, wide cove.

Vakpo Aneta was the largest of the 6 villages, It was a farming settlement on the Have-Kpandu road, at the riverine end of the Dayi branch, 0.5 km south of the road bridge over the Dayi River. During high water periods, the WCP was at a point where the lake was over 150 km wide. But at very low lake level, as in 1979, it was at the bank of the original river channel, less than 15 m across.

B. pfeifferi was occasionally collected by the author in the Dayi River under the road bridge, the same focus reported by Jones (1973). No other focus of *Biomphalaria* has been reported in or near the lake.

Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	5-19 yrs.	WCP location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants, Dec. - Mar., yr. 1	yr. 2	Ceratophyllum, Dec. - Mar., yr. 1	yr. 2	Apr. - Jul., yr. 1	yr. 2
Sodzi Kope	104	Ewe	62.8	76.3	Stream inlet	1/1	1.5	1.2	2.0	1.5	0.2	0.3
Kpeve Tornu	141	Ewe	42.4	67.4	Open shore	2/4	0.2	0.9	0	0	0	0
Woadzi Tornu	72	Ewe	18.4	30.8	Cove	2/4	0.5	0.8	0	0.2	0.1	0
Kpo Kope	49	Ewe	69.2	100.0[a]	Cove	1/1	1.2	1.2	0	0	0	0
Quarters	102	Ewe	70.2	86.7	Cove	1/1	0.8	1.0	0.2	0	0	0
Vakpo Aneta	450[b]	Ewe	-	58.0	River-lake interface	1/1	0.5	0.2	0.5	0.2	0	0

a = < 20 children examined; b = estimate.

Table 41. Epidemiological and ecological features of sampled villages in Dayi branch.

Plate 32. Section of Kpeve Tornu in the Dayi branch.

Plate 33. The WCP at Vakpo Aneta near where the lake meets the Dayi River.

7.4.1 Explanation of snail sampling results (Tables 42 and 43)

The tables highlight the fact that transmission potential was significant only in the December - March season each year, and only at Sodzi Kope, Quarters, Kpo Kope (2nd yr.), and Vakpo Aneta (1st yr.).

The overall mean number of infected snails per WCP was 0.6, and the overall percentage of cercarial-infested WCPs was 11.2%. Excluding the 2 Daka-branch villages, these were the lowest totals in any lake section surveyed.

The reason for the absence of snails in both April - July seasons was that very little, if any, *Ceratophyllum* grew in the littoral zone in these periods, and without emergent vegetation cover, snails could not survive.

Only 20 *B. rohlfsi* were collected from 2 sampled WCPs at Kpeve Tornu, and no specimens were found at Woadzi Tornu. Both of these villages had gravelly shores with little weed growth.

Table 42. Mean number of infected *B. rohlfsi* over mean number of total *B. rohlfsi* collected per WCP by season in Dayi-branch villages, 1978-80.

Village		December - March		April - July		Aug.-Nov.	
		yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	Total
Sodzi Kope		$\frac{4.0}{28.0}$	$\frac{3.2}{23.5}$	$\frac{0}{4.5}$	$\frac{0.3}{2.0}$	$\frac{0.5}{4.5}$	$\frac{1.6}{12.5}$
Kpeve Tornu	1)	$\frac{0}{5.0}$	0	0	0	0	$\frac{0}{1.0}$
	2)	0	0	0	0	0	0
Woadzi Tornu	1)	0	0	0	0	0	0
	2)	0	0	0	0	0	0
Kpo Kope		$\frac{0}{7.2}$	$\frac{8.5}{35.2}$	0	0	0	$\frac{1.7}{8.5}$
Quarters		$\frac{1.0}{5.0}$	$\frac{3.8}{31.2}$	0	$\frac{0.3}{1.0}$	0	$\frac{1.0}{7.4}$
Vakpo Aneta		$\frac{2.0}{19.5}$	$\frac{0}{2.8}$	$\frac{0}{2.5}$	0	0	$\frac{0.4}{5.6}$
Total		$\frac{0.9}{8.1}$	$\frac{1.9}{11.6}$	$\frac{0}{0.9}$	$\frac{0.1}{0.5}$	$\frac{0}{0.8}$	$\frac{0.6}{4.4}$

Table 43. Fraction of cercarial-infested WCPs by season in Dayi-branch villages, 1978 - 1980.

	December - March		April - July		Aug.-Nov.		
Village	yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	Total	%
Sodzi Kope	3/4	3/4	0/4	1/3	1/5	8/20	40.0
Kpeve Tornu	0/8	0/8	0/8	0/6	0/10	0/40	0
Woadzi Tornu	0/8	0/8	0/8	0/6	0/10	0/40	0
Kpo Kope	0/4	3/4	0/4	0/3	0/5	3/20	15.0
Quarters	1/4	3/4	0/4	1/3	0/5	5/20	25.0
Vakpo Aneta	2/4	0/4	0/4	0/3	0/5	2/20	10.0
Total	6/32	9/32	0/32	2/24	1/40	18/160	
%	18.8	28.1	0	8.3	2.5	11.2	

7.5 DESCRIPTION OF VILLAGES IN MID VOLTA SECTION

The 5 sampled villages were along inlets and coves on the eastern side of the mid "trunk" of the Volta Lake (Map 9).

The stretch of shore between Agbenoxoe and Domiabra was heavily populated, with approximately 30 lakeside villages. Thus, the 5 sampled villages represented only about 17% of all settlements along that section. Features of the sampled villages are given in Table 44.

Agbenoxoe was the largest of the 5 villages and was located near the stream end of a deep inlet where the lake was normally about 60 - 100 m across. (A detailed description of the village is given in chapter 9).

The WCP for Kpandu, an indigenous farming village, was the only lake point used by the residents. It was directly across the inlet from Agbenoxoe but was about 2 km from the main part of Kpandu Dafor. After sampling began, it became clear that the WCP was used only during periods of drought. In normal times, the people relied on a stream close to the village. By late 1979, almost all water contact ceased in the lake WCP and snail sampling stopped there in April 1980.

Amedzake Kope was a small fishing and canoe-making village, 1 km from Agbenoxoe, and located at a semi-sheltered point where the inlet was about 1 km across.

Dafor Tornu was a large fishing village about 3 km from Agbenoxoe by canoe journey, and 2 km from Kpandu Dafor along a hilly footpath. The village was located near the mouth of the inlet at an exposed point where the lake was over 2 km wide. The shore was straight and sandy, with little emergent vegetation to reduce wave action.

Domiabra was a fishing village at a sheltered cove, about 30 km north of Agbenoxoe,and a few km north of Kwamekrom, a large resettlement town.

Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	Prev. rate (%) of *S. haematobium*: 5-19 yrs.	WCP location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants, Dec. - Mar., yr. 1	Rooted plants, Dec. - Mar., yr. 2	Ceratophyllum, Dec. - Mar., yr. 1	Ceratophyllum, Dec. - Mar., yr. 2	Ceratophyllum, Apr. - Jul., yr. 1	Ceratophyllum, Apr. - Jul., yr. 2
Agbenoxoe	1086	Ewe[a]	38.0	61.0	Stream inlet	2/4	1.1	0.9	1.4	0.8	0.2	0.5
Kpandu Dafor	900[b]	Ewe[a]	-	-	Stream inlet	1/1	2.0	1.8	1.2	1.0	1.0	-
Amedzake Kope	75	Ewe	89.2	100.0	Wide inlet	2/2	1.0	0.8	1.0	0.1	0	0
Dafor Tornu	312	Ewe	54.3	74.2	Open shore	2/6	0.8	0.5	0	0	0	0
Domiabra	195	Ewe	66.0	89.9	Cove	2/3	1.4	0.8	0	0	0	0

a = indigenous to area; b = estimate.

Table 44. Epidemiological and ecological features of sampled villages in Mid Volta section.

Plate 34. View of the stream inlet of the lake at Agbenoxoe.

7.5.1 Explanation of snail sampling results (Tables 45 and 46).

For the sampled Mid Volta villages as a whole, transmission potential could be described as low to moderate. It was generally highest in each December - March season, and was equally low between April - July and August - November.

At Agbenoxoe, mean numbers of total snails per WCP were relatively high each season, especially in the flood season when the value was the highest of any sampled village around the lake. But mean numbers of infected snails per WCP were relatively low because of little swimming and playing in the water by village residents. The village chief banned swimming after a number of drownings. Adults had little water contact apart from females fetching water. This is reflected in the low *S. haematobium* prevalence rate for all ages.

Some infected snails were collected during the first year at the Kpandu Dafor WCP when human water contact there was still regular. No infected snail was found in the point after August 1979 when regular water contact ceased, even though the WCP was still used as a canoe crossing point to and from Agbenoxoe.

At Amedzake Kope, the prevalence rate was almost 90% for all ages of people, but numbers of infected and total snails were high only in the second December - March season.

Due to the lack of marginal plants and other protection against waves, few *B. rohlfsi* were ever collected at Dafor Tornu. The overall *S. haematobium* prevalence rate of 55.8% among the villagers was higher than expected. However, the author observed that the fisherfolk, including women and children, often made long-lasting fishing trips to other parts of the lake, sometimes to the dangerous Obosum branch.

At Domiabra, transmission potential was intense each December to March, and was virtually absent the rest of the year.

Table 45. Mean number of infected B. rohlfsi over mean number of total B. rohlfsi collected per WCP by season in Mid Volta-branch villages, 1978 - 1980.

Village		December - March		April - July		Aug.-Nov.	Total
		yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	
Agbenoxoe	1)	$\frac{2.5}{45.2}$	$\frac{1.5}{52.5}$	$\frac{0.2}{8.5}$	$\frac{0.3}{11.3}$	$\frac{1.2}{36.4}$	$\frac{1.2}{32.1}$
	2)	$\frac{2.0}{13.2}$	$\frac{0.5}{36.2}$	$\frac{0}{7.8}$	$\frac{2.0}{24.0}$	$\frac{1.6}{11.5}$	$\frac{1.2}{17.4}$
Kpandu Dafor		$\frac{1.8}{14.0}$	$\frac{0}{69.2}$	$\frac{1.8}{31.0}$	-	$\frac{0.2}{12.0}$	$\frac{0.9}{29.8}$
Amedzake Kope	1)	$\frac{1.5}{7.0}$	$\frac{4.8}{39.8}$	0	0	$\frac{0.2}{1.8}$	$\frac{1.3}{9.6}$
	2)	$\frac{0}{1.0}$	$\frac{0}{9.5}$	0	0	0	$\frac{0.2}{2.1}$
Dafor Tornu	1)	$\frac{0}{0.5}$	0	0	0	$\frac{0}{1.2}$	$\frac{0}{0.4}$
	2)	0	0	0	0	0	0
Domiabra	1)	$\frac{4.8}{41.0}$	$\frac{3.8}{58.0}$	0	$\frac{0}{1.0}$	$\frac{0}{0.8}$	$\frac{1.9}{20.9}$
	2)	$\frac{1.2}{26.2}$	$\frac{1.0}{21.0}$	0	$\frac{0}{0.5}$	0	$\frac{0.5}{10.0}$
Total		$\frac{1.5}{16.4}$	$\frac{1.4}{31.7}$	$\frac{0.2}{5.7}$	$\frac{0.3}{5.0}$	$\frac{0.4}{6.6}$	$\frac{0.7}{10.4}$

Table 46. Fraction of cercarial-infested WCPs by season in Mid Volta-branch villages, 1978 - 1980.

	December - March		April - July		Aug.-Nov.		
Village	yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	Total	%
Agbenoxoe	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{8}$	$\frac{3}{6}$	$\frac{4}{10}$	$\frac{16}{40}$	40.0
Kpandu Dafor	$\frac{2}{4}$	$\frac{0}{4}$	$\frac{2}{4}$	-	$\frac{0}{5}$	$\frac{4}{17}$	23.5
Amedzake Kope	$\frac{2}{8}$	$\frac{4}{8}$	$\frac{0}{8}$	$\frac{0}{6}$	$\frac{1}{10}$	$\frac{7}{40}$	17.5
Dafor Tornu	$\frac{0}{8}$	$\frac{0}{8}$	$\frac{0}{8}$	$\frac{0}{6}$	$\frac{0}{10}$	$\frac{0}{40}$	0
Domiabra	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{0}{8}$	$\frac{0}{4}$	$\frac{0}{10}$	$\frac{12}{38}$	31.6
Total	$\frac{14}{36}$	$\frac{14}{36}$	$\frac{3}{36}$	$\frac{3}{22}$	$\frac{5}{45}$	$\frac{39}{175}$	
%	38.9	38.9	8.3	13.6	11.1	22.3	

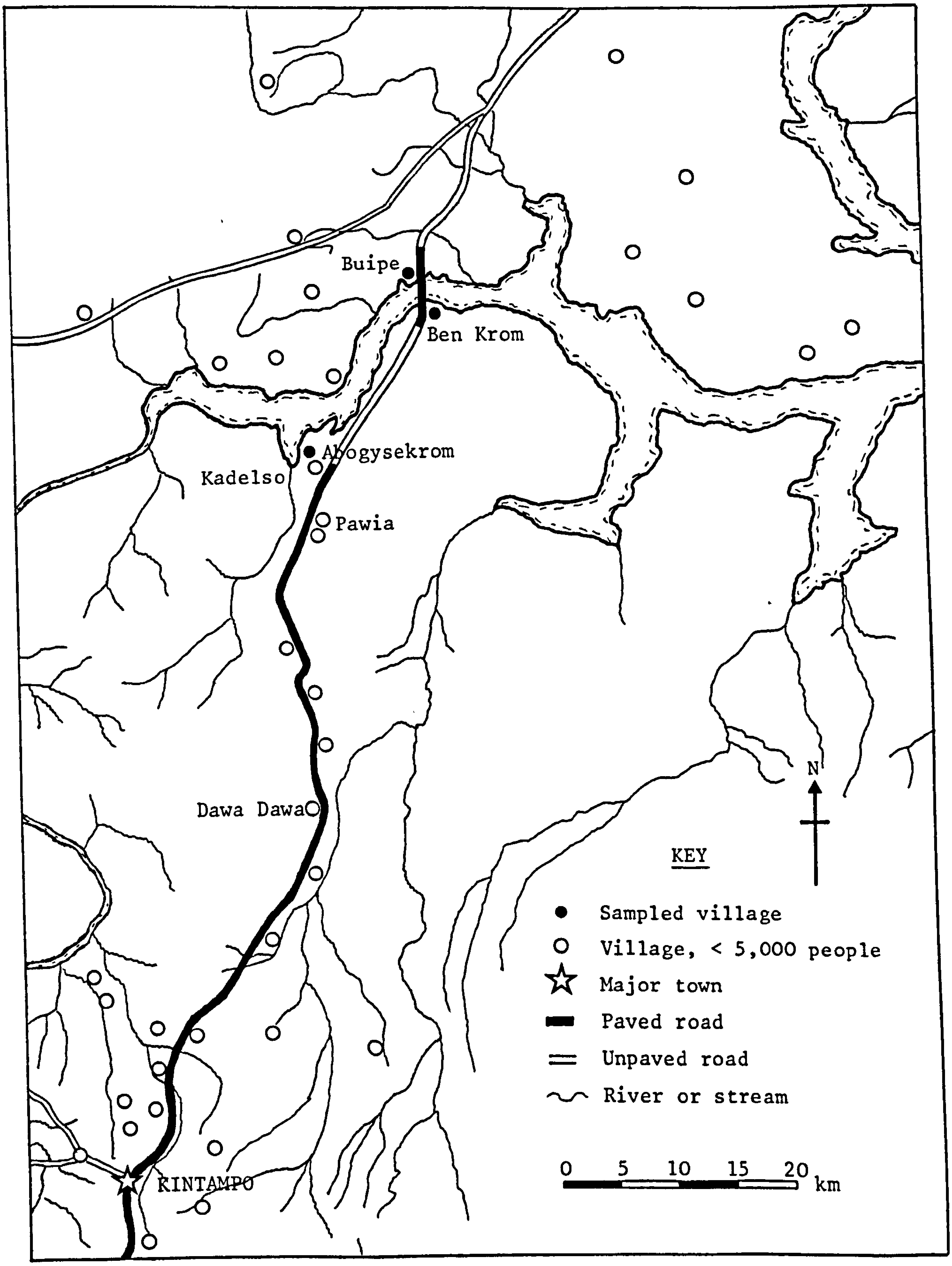
7.6 DESCRIPTION OF SAMPLED VILLAGES IN BLACK VOLTA BRANCH

The 3 sampled villages were on or near the main Kintampo-Tamale road. There was only 1 other accessible lakeside village nearby, which was discovered near the end of sampling. The area away from the road was sparsely populated (Map 10).

Abogysekrom was a small fishing and alcohol distilling village of Ewes near the end of a narrow, shallow stream inlet of the main Black Volta branch. It was 2 km north of the farming village of Kadelso where about 2000 people lived.

Ben Krom was a fishing and alcohol producing village of about 400 residents, mostly Ewe. It was at the southern end of the road bridge spanning the Black Volta branch, and which separated the Brong-Ahafo Region from the Northern Region. At that point, the lake was normally 300 - 400 m wide. The sampled WCPs were on a flat, clay-like section of shore, usually overgrown with Polygonum from August to March.

Buipe was a large fishing and trading village of Ewe, Ada, and Moslem tribes on the northern end of the bridge. The road divided the village into 2 parts. Snail sampling and the prevalence survey were conducted in the larger, western side.



Map 10

Sampled villages at the Black Volta branch of the Volta Lake.

Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	5-19 yrs.	WCP location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants, Dec. - Mar., yr. 1	yr. 2	Ceratophyllum, Dec. - Mar., yr. 1	yr. 2	Apr. - Jul., yr. 1	yr. 2
Abogysekrom	106	Ewe	55.2	71.4	Stream inlet	1/2	1.5	1.8	0	0	0	0
Ben Krom	400[a]	Ewe	-	-	Flat shore; old Volta R. flood plain	2/5	0.6	3.0	0	0	0	0
Buipe (west)	488[a]	Mixed	65.9	88.9	Pockets off old Volta R. flood plain	2/2	1.5	2.0	0	0	0	0

a = estimate.

Table 47. Epidemiological and ecological features of sampled villages in Black Volta branch.

Plate 35. The main WCP at Abogysekrom during the dry season. The point was also used for distilling "Akpeteshie", a popular, intoxicating drink.

Plate 36. The second main WCP at Buipe (WCP 2), located in a pocket off of the riverine Black Volta branch, near the road bridge separating the Brong-Ahafo and Northern Regions.

7. 6.1 Explanation of snail sampling results (Tables 48 and 49)

At Buipe, transmission potential was intense each December - March and in April - June 1980. At Abogysekrom, the potential was significant only during the first December - March season. At Ben Krom, just 1 *B. rohlfsi* was collected.

All 3 villages were located in a hot part of Ghana where mid-day air temperature is usually around 37°C from January to July. Although not measured, surface water temperature in the WCPs at Abogysekrom and Ben Krom during April - July seemed by touch to be at least 36°C. WCPs in the latter 2 villages were also turbid from much clay in the drawdown zone, and in both villages, were located on flat shores where small fluctuations in lake level caused considerable movement in WCP position. Except for the first December - March season at Abogysekrom (when the WCPs contained a 2.0 rank of *Polygonum* in December and January, and water temperature was seasonally cooler), the combination of high water temperature, turbidity, and shifting shorelines could have controlled populations of *B. rohlfsi* in the 2 villages.

At Buipe, the drawdown slope was steeper, and there seemed to be less surface clay. Both sampled WCPs were sheltered by side boundaries of emergent weeds during at least part of both December - March seasons; one WCP contained the rooted weeds from September 1979 to June 1980. Human water contact was intense in both WCPs, and urination in the main WCP by men and children was occasionally observed during snail sampling.

Table 48. Mean number of infected B. rohlfsi over mean number of total B. rohlfsi collected per WCP by season in Black Volta-branch villages, 1978 - 1980.

Village		December - March		April - July		Aug.-Nov.	Total
		yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	
Abogysekrom		3.5/19.2	0/1.2	0	0.3/0.3	0	0.9/5.2
Ben Krom	1)	0/0.2	0	0	0	0	0/0.1
	2)	0	0	0	0	0	0
Buipe	1)	4.2/17.0	5.0/20.8	0	2.0/7.3	0	2.7/10.5
	2)	3.5/25.5	0.2/1.0	0	2.7/7.7	0	1.4/8.1
Total		2.2/12.2	1.2/5.2	0	1.2/3.8	0	1.1/5.2

Table 49. Fraction of cercarial-infested WCPs by season in Black Volta-branch villages, 1978 - 1980.

Village	December yr. 1	March yr. 2	April yr. 1	July yr. 2	Aug.-Nov. yr. 1+2	Total	%
Abogysekrom	3/4	0/4	0/2	1/3	0/3	4/16	25.0
Ben Krom	0/8	0/5	0/4	0/3	0/6	0/26	0
Buipe	6/8	5/8	0/4	4/6	0/6	15/32	46.9
Total	9/20	5/17	0/10	5/12	0/15	19/74	
%	45.0	41.7	0	29.4	0	25.7	

7.7 DESCRIPTION OF SAMPLED VILLAGES IN PRU BRANCH

The 5 sampled villages were all on the accessible, northern side of the branch, on or near the Kumasi-Yeji road, and represented 50% of all lakeside villages on that shore (Map 11). There were about 27 total villages on both banks. Results from the sampled communities probably give an accurate picture of the full range of transmission potential that existed at the entire northern shore.

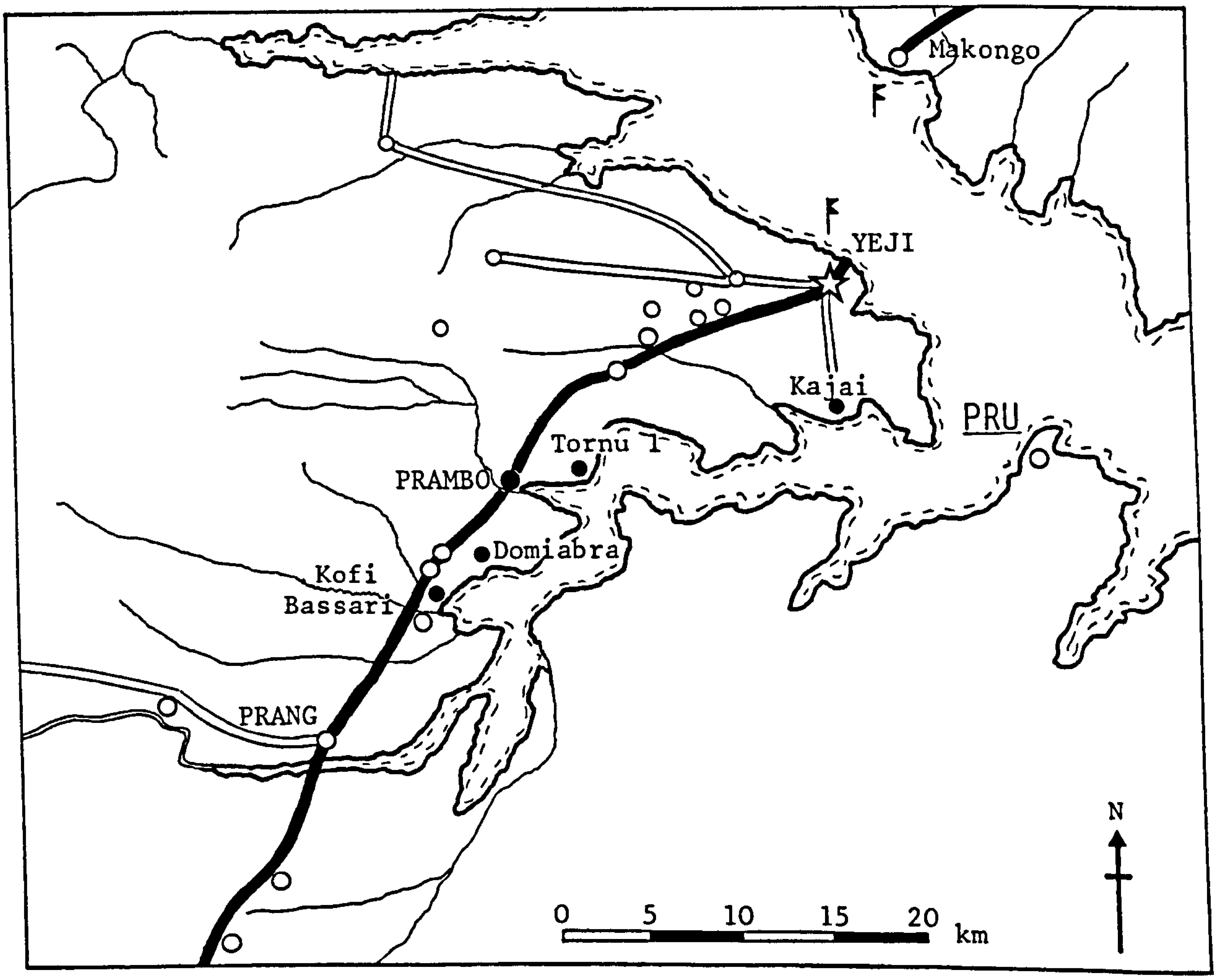
Kofi Bassari was a large Ewe fishing village. It attracted fish mongers from as far away as Kumasi for daily business. According to the village chief, *Ceratophyllum* infested parts of the limnetic and littoral zones for the first time ever in late 1978. By 1980, it was well established in WCPs, giving rise to large populations of *B. rohlfsi* and intense transmission of *S. haematobium*.

Domiabra had a population of over 60 Ewe and Ada fisherfolk when sampling started. By the end of 1979, only 22 people remained.

Prambo was a commercial town of about 4000 people. The sampled WCP was the only point of significance used by the town people. It was at a stream inlet, where part of the old, tarred, "Yeji" road was cut-off by the lake. When the lake was unusually low in 1978 and 1979, the original road bridge was above water for the first time since 1966, and was a point of heavy water contact by hundreds of people.

Tornu No. 1 was a large Ewe fishing village along a wide, exposed section of the Pru branch. It is probable that *Ceratophyllum* infested part of the littoral zone for the first time ever in December 1979; but the weed was at least temporarily washed away in March 1980.

Kajai was a village of indigenous Nchumburu farmers and semi-nomadic Ewe fisherfolk. It was located near the mouth of the Pru branch, and its WCPs were often exposed to heavy wave action.



KEY

● Sampled village or town
○ Village, < 5,000 people
☆ Town, > 10,000 people
River or stream
Paved road
Unpaved road
Ferry crossing

Map 11

Sampled villages in the Pru branch of the Volta Lake.

Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	5-19 yrs.	WCP location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants, Dec. - Mar., yr. 1	yr. 2	Ceratophyllum, Dec. - Mar., yr. 1	yr. 2	Apr. - Jul., yr. 1	yr. 2
Kofi Bassari	578	Ewe	40.8	54.3	Stream inlet	2/5	0.8	2.1	0.8	1.8	0	3.0
Domiabra	22-60	Ada	-	-	Flat, weedy shore	1/1	3.0	3.0	0.5	0	0	0
Prambo	4000[a]	Mixture	-	70.7	Stream inlet	1/1	2.5	0.8	0	0	0	0
Tornu No. 1	304	Ewe, Fanti	39.1	55.1	Open shore	1/4	0	0	1.8	0	0	0
Kajai	450[a]	Nchumburu, Ewe	-	-	Open shore	1/5	0	0.8	0	0	0	0

a = estimate.

Table 50. Epidemiological and ecological features of sampled villages in Pru branch.

Plate 37. The weedy WCP at Domiabra in November 1978 before most of the villagers moved away. Due to the flat shore, the WCP often moved over 50 m between consecutive months.

Plate 38. The main WCP at Prambo in November 1978 when many B. rohlfsi were collected from Polygonum, the dominant weed in the picture.

Plate 39. The main WCP at Prambo in November 1979 after the lake rose 5 m from July - November.

Plate 40. The main WCP at Prambo in June 1980.

7.7.1 Explanation of snail sampling results (Tables 51 and 52)

During the first year, a significant transmission potential existed at Prambo, Domiabra, and Kofi Bassari from December - March. After that (as in all northern branches surveyed), not a single B. rohlfsi was collected in any village until the following December. From April to July 1979, the very low lake level turned all WCPs into points on barren shores without any aquatic weed growth. The main WCP at Prambo turned into a mud hole; the entire stream inlet around Prambo dried up. The following lake rise was another catastrophy for B. rohlfsi.

By December 1979, Ceratophyllum grew in a dense mass in the littoral zone at Kofi Bassari and was scattered along the shore at Tornu No. 1. This led to a rapid build-up of B. rohlfsi in the 2 villages - starting in January at Tornu No. 1 and February at Kofi Bassari. Although the weed and the snail lasted no longer than March in WCPs at Tornu No. 1, Ceratophyllum and B. rohlfsi remained in heavy density at Kofi Bassari, and infected snails were found there every month through June.

The prevalence rate of S. haematobium for 5 - 19 year-old children at Kofi Bassari was 54.3% when the survey took place in March 1980. Thus, the results would not have reflected the observed upsurge in transmission potential. However, as late as 1972, the prevalence rate among 5 - 14 year-olds in the village was only 5.5% (Jones, 1973).

Populations of B. rohlfsi expanded slowly at Prambo in 1980. The previous flooding led to reduced emergent weed growth in the second year, but infected B. rohlfsi were collected from the WCP every month in 1980 from February to June.

At Kajai, only 10 B. rohlfsi were found (1 infected), all in January 1980.

Table 51. Mean number of infected <u>B. rohlfsi</u> over mean number of total <u>B. rohlfsi</u> collected per WCP by season in Pru-branch villages, 1978 - 80.

Village		December - March yr. 1	December - March yr. 2	April - July yr. 1	April - July yr. 2	Aug.-Nov. yr. 1+2	Total
Kofi Bassari	1)	1.0/14.5	11.5/31.5	0	8.7/31.3	0/1.0	4.8/17.5
	2)	0.5/18.0	2.8/34.5	0	3.3/22.3	0	1.4/17.3
Domiabra		2.0/11.5	0/1.0	0	0	0	0.5/3.1
Prambo		11.5/113.5	2.0/5.8	0	2.7/21.7	0/26.3	3.9/38.8
Tornu No. 1		0	1.2/29.5	0	0/5.3	0	0.1/8.4
Kajai		0	0.2/2.5	0	0	0	0.1/0.6
Total		2.5/26.2	3.0/17.5	0	2.4/13.4	0/5.5	1.9/14.8

Table 52. Fraction of cercarial-infested WCPs by season in Pru-branch villages, 1978 - 1980.

Village	December - March		April - July		Aug.-Nov.	Total	%
	yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2		
Kofi Bassari	3/8	4/8	0/4	4/6	0/6	11/32	34.4
Domiabra	2/4	0/4	0/2	0/3	0/3	2/16	12.5
Prambo	4/4	2/4	0/2	3/3	0/3	9/16	56.2
Tornu No. 1	0/4	1/4	0/2	0/3	0/3	1/16	6.2
Kajai	0/4	1/4	0/2	0/3	0/3	1/16	6.2
Total	9/24	8/24	0/12	7/18	0/15	24/93	
%	37.5	33.3	0	38.9	0	25.8	

7.8 DESCRIPTION OF SAMPLED VILLAGES IN THE OTI BRANCH

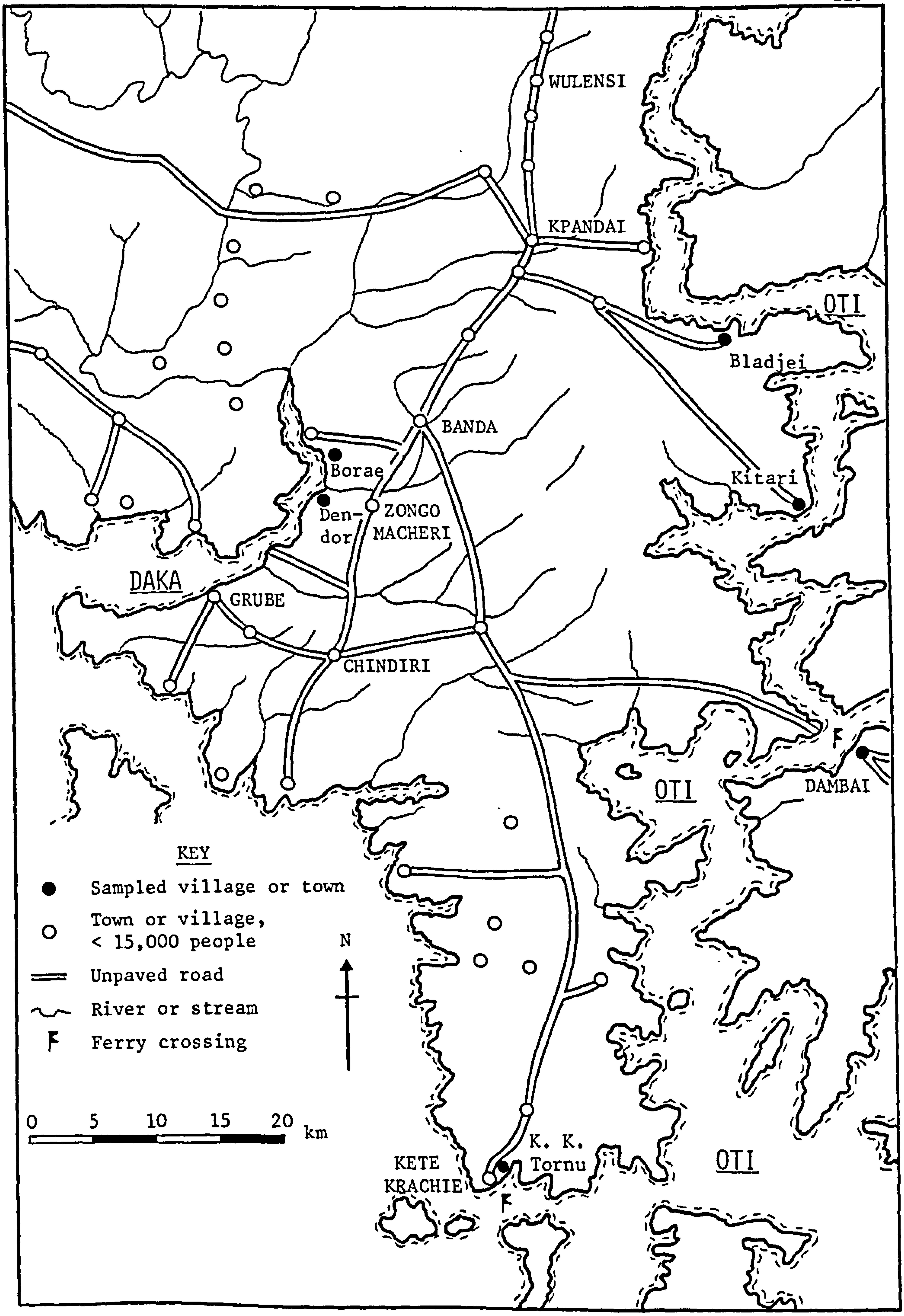
There were few roads in this part of Ghana and the 5 sampled communities were among the most accessible (Map 12). There were over 50 other, remote lakeside villages on the west shore of the branch between Bladjei and Kete Krachie. Therefore, data collected would not necessarily give an accurate picture of the range of transmission potential that existed in the branch as a whole.

Bladjei was an old farming village of Nchumburus, but because of the lake, had an Ewe and Efutu fishing community. VRA resettlement houses were built in the village,but most were unoccupied. *Ceratophyllum* appeared in the sampled WCPs from December 1979 to March 1980, the first time the weed had been recorded in the village since about 1972 (Odei, personal communication).

Kitari was another old Nchumburu farming village. The shore was gravelly, devoid of much emergent vegetation, and exposed to wave action.

Kete Krachie Tornu was a fishing village of Ewes at a cove on the northeastern limit of the town of Kete Krachie. The sampled WCP was similar to WCPs at other small fishing villages which fringed Kete Krachie town and which probably accounted for most *S. haematobium* in the greater town area. The main WCPs of the town itself were at or near a large landing spot for tour boats, barges, and ferries, and were unsuitable for *B. rohlfsi* due to diesel and oil pollution. One could argue that the Kete Krachie area was actually closer to the old Volta River than to the Oti section of the lake. But for convenience, it has been included as part of the Oti branch.

Dambai was a commercial town of about 4000 people at the main ferry crossing point to and from northeastern Ghana. The ferry was out of action much of the time during 1979 and 1980, and this restricted snail sampling to 10 months at the designated WCP. This was the main WCP for the town, and was located less than 100 m from the ferry landing.



Map 12

Sampled villages and towns in the Oti and Daka branches of the Volta Lake.

Village	Population: 1978-80	Main tribe(s)	Prev. rate (%) of *S. haematobium*: All ages	5-19 yrs.	WCP location	No. WCPs sampled per total in use	Mean density rank of weeds in sampled WCPs (0 - 3 scale): Rooted plants Dec. - Mar. yr. 1	yr. 2	Ceratophyllum Dec. - Mar. yr. 1	yr. 2	Apr. - Jul. yr. 1	yr. 2
Bladjei	900[a]	Nchumburu, Ewe, Efutu	-	80.6	Open shore	2/4	0.7	1.7	0	1.5	0	0
Kitari	800[a]	Nchumburu	-	35.3	Open shore	2/5	0	0.4	0	0	0	0
Kete Krachie Tornu	200[a]	Ewe	-	58.3[b]	Small cove	1/1	0.8	1.0	0	0	0	0
Dambai	4000[a]	Mixture	-	-	Semi-sheltered pocket	1/>8	1.0	1.0	0	0	0	0

a = estimate; b = prevalence survey at nearby school which included other residents of area.

Table 53. Epidemiological and ecological features of sampled villages in Oti branch.

Plate 41. The exposed, bare shore at Kitari in the Oti branch which was similar in ecology to many shores in the Daka branch.

Plate 42. The main WCP at Dambai, near the ferry landing.

7.8.1 Explanation of snail sampling results (Tables 54 and 55)

All snails were collected in the 2 December - March seasons. Transmission potential was most widespread in the second year when more WCPs contained weeds. Although only 6 WCPs were sampled, it is probable that because of the savannah ecology and limited distribution of *Ceratophyllum*, almost all local transmission of *S. haematobium* in the Oti branch is normally confined to the above season.

Greatest numbers of total and infected *B. rohlfsi* were found at Bladjei, mainly from *Ceratophyllum* which first appeared in December 1979, and which remained to March 1980.

At Kitari, all 14 snails collected (5 infected) were found in January 1980, from a temporary patch of *Polygonum*. The shore and littoral zone were otherwise free of weed growth.

At Kete Krachie Tornu, emergent weed growth was limited to September to February each year. A total of 30 snails were collected in the 2 December to February periods, mostly from the only weed found in the WCP - *Paspalum*.

There may have been high transmission at Dambai during much of the second December - March season. The one sampling effort in this period, in January 1980, yielded 62 *B. rohlfsi*, 11 infected.

Table 54. Mean number of infected B. rohlfsi over mean number of total B. rohlfsi collected per WCP by season in Oti-branch villages, 1978 - 80.

Village		December - March		April - July		Aug.-Nov.	
		yr. 1	yr. 2	yr. 1	yr. 2	yr. 1+2	Total
Bladjei	1)	$\frac{0.7}{14.0}$	$\frac{14.3}{45.0}$	0	0	0	$\frac{3.5}{13.6}$
	2)	$\frac{0}{12.0}$	$\frac{6.0}{30.3}$	0	0	0	$\frac{1.4}{9.8}$
Kitari	1)	0	$\frac{1.7}{4.7}$	0	0	0	$\frac{0.4}{1.1}$
	2)	0	0	0	0	0	0
Dambai		$\frac{0.3}{3.3}$	$\frac{11.0}{62.0}$[a]	0	0[b]	0	$\frac{1.2}{7.2}$
K. Krachie Tornu		$\frac{2.0}{7.3}$	$\frac{1.3}{2.7}$	0	0	0	$\frac{0.8}{2.3}$
Total		$\frac{0.5}{6.1}$	$\frac{5.1}{19.4}$	0	0	0	$\frac{1.2}{5.6}$

a,b = sampling conducted only in January and April, 1980 respectively.

Table 55. Fraction of cercarial-infested WCPs by season in Oti-branch villages, 1978 - 1980.

Village	December - March yr. 1	December - March yr. 2	April - July yr. 1	April - July yr.2	Aug.-Nov. yr. 1+2	Total	%
Bladjei	1/6	5/6	0/4	0/4	0/6	6/26	23.1
Kitari	0/6	1/6	0/4	0/4	0/6	1/26	3.8
Dambai	1/3	1/1	0/2	0/1	0/3	2/10	20.0
K. Krachie Tornu	2/3	1/3	0/2	0/2	0/3	3/13	23.1
Total	4/18	8/16	0/12	0/11	0/18	12/75	
%	22.2	50.0	0	0	0	16.0	

7.9 DESCRIPTION OF SAMPLED VILLAGES AND SNAIL SAMPLING RESULTS IN THE DAKA BRANCH

Due to limitation of time and poor roads, only 2 villages could be sampled in the Daka branch (Map 12). The entire lake section was characterized by a gravelly, exposed shore with little emergent weed growth and no significant Ceratophyllum. Because of this, there was probably no significant transmission of S. haematobium occurring anywhere in the branch.

No B. rohlfsi was found in the 2 sampled villages. During a reconnaissance trip to the branch in November 1978, 4 other villages were searched for the snail, but none was found. Although Jones (1973) reported finding B. rohlfsi in the Daka branch between 1970 and 1973, none was infected with S. haematobium. Jones (ibid) recorded very low S. haematobium prevalence rates among indigenous children from the area.

Borae and Dendor were both old, Nchumburu farming villages with some Ewe fisherfolk, and were located at the riverine end of the branch. The shore in both villages was gravelly, although Polygonum grew in a 2.0 density rank at Borae in the first December - March season. The S. haematobium prevalence rate among 5 - 19 year-old children at Borae was only 8.4%. Because of a serious tribal dispute between the land-owning Nchumburus and Konkomba squatters, a prevalence survey could not be conducted at Dendor.

CHAPTER 8

GENERAL EPIDEMIOLOGICAL FINDINGS ON S. HAEMATOBIUM AROUND THE LAKE

8.1 INTRODUCTION

An important part of the present study was to collect information on S. haematobium prevalence rates and densities of egg output among people in lakeside villages where snail sampling was conducted. A presentation of these epidemiological findings is given in this chapter.

Results have been analysed to provide practical information on the status of infection in up to 30 of the 39 study villages, and in groupings of villages in different parts of the lake. Where relevant, current findings are compared with results from the WHO project in Ghana and from the original surveys conducted around the lake by the VLRP (Jones, 1973).

From the present results, it was possible to gain original information on the dynamics of transmission in the lake by use of catalytic models. It was also possible to ascertain for the first time in Ghana the relative importance of each age group in regard to their contamination potential.

One of the main contributions of the study was the adaptation of the "Nuclepore" filtration technique for use in a large-scale field survey of S. haematobium - the first time this was done.

Before the epidemiological results is a description of the "Nuclepore" filtration method, how it was adapted for use at the Volta Lake, and how it compared with the filtration technique used in the WHO project.

8.2 MATERIALS AND METHODS

8.2.1 Description of the Nuclepore technique and how it was adapted for use in Ghana.

Introduction

Since the introduction of filtration techniques as an alternative to sedimentation for quantitative examination of S. haematobium eggs in urine samples, improvements have been made in filtration hardware, filter paper, and staining reagents (Bradley, 1968; Dazo and Biles, 1974; Scott, Senker, and England, 1982).

The drawbacks of the standard filtration methods are that they require a well-equipped laboratory, electricity, are time consuming, and because cellulose-based filters are used, require staining, which obscures differentiation between calcified and viable eggs.

These drawbacks were largely eliminated with the introduction of the "Nuclepore" filtration technique for detection of S. haematobium eggs, described by Peters, Warren, and Mahmoud (1976). With this method, urine samples could be collected, processed, and eggs counted quantitatively in the field - each in a few minutes. The key to this improvement was that the filter membranes were made of thin, perforated polycarbonate which allowed schistosome eggs to stand out clearly without differential staining. Viable and non-viable eggs were more easily distinguished.

As described (ibid), urine samples were injected with separate disposable syringes (without needles) through PT-103 chambers ("Swin-Lok" or "Swinnex"), each containing a Nuclepore filter of 13 mm diameter and 8 μm pore-size. When chambers were opened, the filters were removed with forceps, placed face down on 3 x 1" microscope slides, allowed to dry (for firm adhesion to the slides and prevention of miracidial hatching), and then either examined microscopically on the spot, or stored in a slide box for later scanning. To improve egg visibility and counting accuracy, a drop of saline was placed on the filter just before examination, and covered by a transparent graticule.

It was claimed (ibid) that for negative samples or those with light egg densities, filters could be scanned completely in 4 passes (40 x magnification) in a matter of seconds.

But with the above technique, about 5% of 5 or 10 ml urine samples could not be fully injected through the polycarbonate filters due to clogging. The membranes were also expensive, each costing US $ 0.14 in 1976[a].

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[a] The unit cost of pre-cut, 25 mm, 12 μm filters in 1979 was US $ 0.15. At present, the unit price is about $ 0.32, but large uncut sheets are available at a lower proportional price. It should be possible to recycle used membranes by soaking them in cleaning/digesting solvents. However, the membranes are fragile and tear easily.

Because of the speed and practicality of the Nuclepore technique, the author decided to use it at the Volta Lake if initial trials in Ghana proved successful.

The first trials were very successful and the Nuclepore method became the method of choice. The trials demonstrated that clogging could be expected to occur in over 10% of 10 ml samples if filters of 8 µm pore-size were used. However, clogging could be eliminated by using 25 mm diameter, 12 µm filters. These larger filters were used in all subsequent prevalence/intensity surveys, and in over 4000, 10-ml urine samples injected, not a single case of clogging occurred even though many people had urinary tract infections, gross haematuria, and/or various crystals in their urines.

Equipment

For maximum daily work in a village, 150 plastic "Swin-Lok" chambers containing the filters were packed in small cardboard boxes and were carried in a medium-sized travelling bag also containing enough recording forms, wax pencils, pens, chalk, forceps, soap, and tissue paper. Another medium-sized travelling bag carried about 160 clean urine cups and syringes repectively. After specimens were collected, the dirty cups and syringes were carried away in a separate basket. One ordinary compound microscope with associated items for examining the filters was always taken on trek but normally not taken to a lakeside village.

Procedure for registering people and collecting urine

Before a village was to be surveyed for S. haematobium infection in the human population, the chief or headman was consulted during times of snail sampling to agree upon a date when most people would be in the village. (Except for school surveys, the best day was a Sunday.) The purpose of the survey was explained, and it was stressed that the information gathered would be given to the Ghana Ministry of Health, to help the Ministry's long-term objective of expanding chemotherapy around the Volta Lake and elsewhere in Ghana. In all cases, the villagers cooperated fully.

On the agreed day, urine was collected between 1000 - 1400 h. In villages with less than 150 people, registration and urine collection could be completed in the same day with effort by the 4-man team. For this, registration often had to begin before 0700 h, when participants were reminded to be available at the designated time. The team went to each compound recording on mimeographed forms the name, age, sex, and tribe of each person as well as relationship to the family head (Appendix C). For those people who did not know their age, the author made a reasonable guess. As part of the census, each surveyed compound was numbered by chalk.

In villages with more than 150 people, 2 or 3 visits were normally required to complete registration and urine collection. In villages with 200 - 400 people, samples were usually taken from every second compound; in villages with 400 - 700 people, they were taken from every third compound. With few exceptions, the biggest villages and towns were surveyed by examining between 100 - 150 school children between the ages of 5 and 19, in 1 or 2 schools in the respective communities.

Method of urine collection

At each sampled compound, the name of each person was called. Each person received a clean plastic cup with his or her number marked boldly in 2 places. Children under 2 years of age were assisted by parents or relatives. It normally took only a few minutes for people to produce urine specimens. When ready, the samples were placed on a small table, always provided for the team by each family. As soon as a urine cup was placed on the table, the author extracted 10 ml with a clean syringe, first agitating the specimen by pumping the syringe in and out a few times to scatter the eggs.

Each 10 ml sample was injected through an appropriately numbered chamber containing the Nuclepore filter. This was done over the urine cup so that the untrapped liquid fell back into it. To be sure that no excess urine remained in the chamber, the same syringe was used to blow air through the chamber, 2 to 3 times. This was done gently to prevent any eggs from being blown to the perimeter of the filter. When ready, each chamber was placed in the designated, cardboard box.

The samples could be kept in the chambers at least one week without decay or significant egg hatching; but normally, the chambers were opened in a laboratory or rest house within a few hours of sample collection.

Each filter was placed face down on the centre of a clean 3 x 1" microscope slide, and the code number marked boldly on both ends of the slide. It was advisable to allow filters to dry on the slides for about 30 minutes before examination. This not only prevented eggs from hatching upon subsequent moistening of the filters with water, but allowed any grains of dirt or sand to be blown-off the filters in the dry state without the filters moving. Large impurities would limit clear visibility unless the graticule was pressed firmly on the slide. This could cause slide-breakage or graticule-scratching.

Slides with filters could be easily packed in specially-designed slide boxes and brought to Accra or Agbenoxoe without the filters coming loose.

The opened chambers, dirty syringes, and dirty urine cups were soaked in Teepol solution, rinsed repeatedly in fresh water, and allowed to dry in the sun or indoors on paper towels. With 2 men working, all 150 chambers could be reassembled with new filters in about 45 minutes. Even with repeated cleaning, the chambers remained like new throughout the 20 months of use. Syringes were replaced every few months, as soon as they became stiff. Spot checks were made periodically to detect possible contamination by old eggs in the reused equipment, but no such contamination was ever found.

Microscope examination

Slides with filters were moistened with a drop of water, covered with a transparent counting graticule, and eggs enumerated with a tally counter. Eggs appeared remarkably clear. With the 25 mm-diameter filters and the graticule grid-size used, at least 8 scanning passes were necessary under 50 x magnification for full examination. The entire filter was examined if less than 150 eggs were counted after the first half of the filter was read; if their number was over 150, the result was multiplied by 2. When egg density appeared to be over 2,000 at first glance, only one quadrant of the filter was read and the result multiplied by 4. Even with extremely large numbers of eggs per filter (in one case over 25,000), it was possible to make accurate counts per square of the graticule.

Negative samples and filters with fewer than about 50 eggs took less than 1 minute to read. Filters with over 4000 eggs took as long as 7 minutes to complete. The average number of filters which the author could finish in 1 hour of uninterrupted work was about 20, or 1 filter every 3 minutes.

With careful removal of the graticule, slides with filters could be re-examined at later dates with only slight loss of eggs and reduction in clarity.

8.2.2 Comparison of the Nuclepore technique with the filtration method used in the WHO project in Ghana

Details of the filtration method maintained in the WHO project were described by Scott et al. (1982). Simply stated, urine samples were collected in villages with 370 ml plastic beakers, covered with snap-on lids, and then transported a few hours later to the Anyaboni laboratory. There, 5 ml samples were taken from the beakers using one automatic syringe (rinsed 2 - 3 times in one large beaker of water between the samples) and injected in specimen bottles containing 5 ml of 1% aqueous carbol fuchsin solution. These were appropriately numbered, capped, and sent to Accra for later examination. Filtration was performed using the Millipore apparatus with electric pumps, and the liquid contents passed through Whatman's No. 1 filter paper, 47 mm in diameter. The filter papers were subsequently examined microscopically in a moistened state, under a transparent graticule.

The purpose of the present experiment was to compare the agreement between the Nuclepore and WHO-project techniques in detecting positivity of *S. haematobium*, and numbers of eggs, when aliquots were taken together from 149 urine samples.

Materials and methods

The 149 urine samples were collected on the same day from known, untreated children who lived around the new man-made Weija Lake near Accra. A few hours after collection, the specimens were in the Accra laboratory, ready for sub-samples to be taken.

Just after each specimen was thoroughly agitated to randomize eggs, 5 ml of urine was removed by the standard procedure used in the WHO project. Then, 10 ml was removed with a clean syringe according to the Nuclepore method, processing being done in the normal way for both.

The Nuclepore filters were examined independently by the author and an assistant. The set of Whatman filters were examined independently by 2 experienced Ministry of Health technicians, under the supervision of E.C. England, WHO Technical Officer.

The results which follow are a comparison of the mean values from each method, but with mean counts from the Whatman filters multiplied by 2 so that all values are expressed as number of eggs per 10 ml.

Ten ml sub-samples were not taken in the first place by the WHO-project method because the automatic syringe only went up to 5 ml, and it was thought best not to alter the standard method.

Results

It can be seen from Table 57 that the Nuclepore method detected slightly fewer positive samples than the WHO-project method but showed a slightly higher geometric mean of egg counts in positive samples.

Table 57. Comparison of the 2 methods in detection of positivity of *S. haematobium*, and in the geometric mean egg output (per 10 ml) in paired samples.

	Nuclepore method	WHO-project method
No. of samples with 1 or more eggs	110	117
No. of total samples	149	149
% of positive samples	73.8	78.5
Geometric mean of egg counts in + samples, ± s of logs	62.2 ±.92	50.9 ±.79

To see whether the WHO-project method detected significantly more positive samples than the Nuclepore method, McNemar's test can be applied as shown in the calculations following Table 58.

Table 58. Number of positive and negative samples detected by both methods.

Type	WHO-project method	Nuclepore method	Number of pairs
1	+	+	106 (k)
2	+	-	11 (r)*
3	-	+	4 (s)
4	-	-	28 (m)

* In 3 samples detected as positive by the WHO-project method, only 1 egg was seen (per 5 ml) by one of the two examiners.

The null hypothesis that r - s/N = 0 is tested by the normal standard deviate with r -(0.5 n) reduced by 0.5 (continuity correction) where n = r + s.

$$u = \frac{r - (0.5\ n) - 0.5}{0.5\ \sqrt{n}} = \frac{11 - 7.5 - 0.5}{0.5\ \sqrt{15}} = 1.55$$

Since u = 1.55 is less than u = 1.96 (P = 0.05), the observed differences between r and s are not significant at the 95% confidence level. Thus, the 2 filtration methods were about equal for qualitative determination of positive and negative samples.

To test whether there was any significant difference between the egg counts of the agreed pairs of samples (k), parameters of the logarithms of the postive counts are compared by the t test for paired means, as shown from summary results in Table 59.

Table 59. Total results of sums, means, and differences of the logarithms off egg counts in 106 samples detected as positive by both methods.

	Nuclepore method X1	WHO-project method X2	Difference $D = X1 - X2$	Deviation $d = D - \bar{D}$	Squared deviation d^2
Total of logs (n = 106)	195.877	192.856	3.021	- 0.662	24.757
Mean	1.848	1.819	$\bar{D} = 0.029$		$S_D2 = 0.236$
Values of $S_{\bar{D}}2$ and $S_{\bar{D}}$			$S_{\bar{D}}2 = .236/106 = 2.23 \times 10^{-3}$		$S_{\bar{D}} = 0.047$

$$t = \bar{D} / S_{\bar{D}} = 0.029/0.047 = 0.617$$

Since t is less than 1.980 (P = 0.05) for 105 d.f., the above results indicate no significant different in egg counts by the 2 filtration methods.

Plate 43. Registering people and collecting urine at Kofi Bassari. All of the equipment necessary to collect and inject 150 different samples through Swin-Lok chambers could be fitted into the 2 travelling bags.

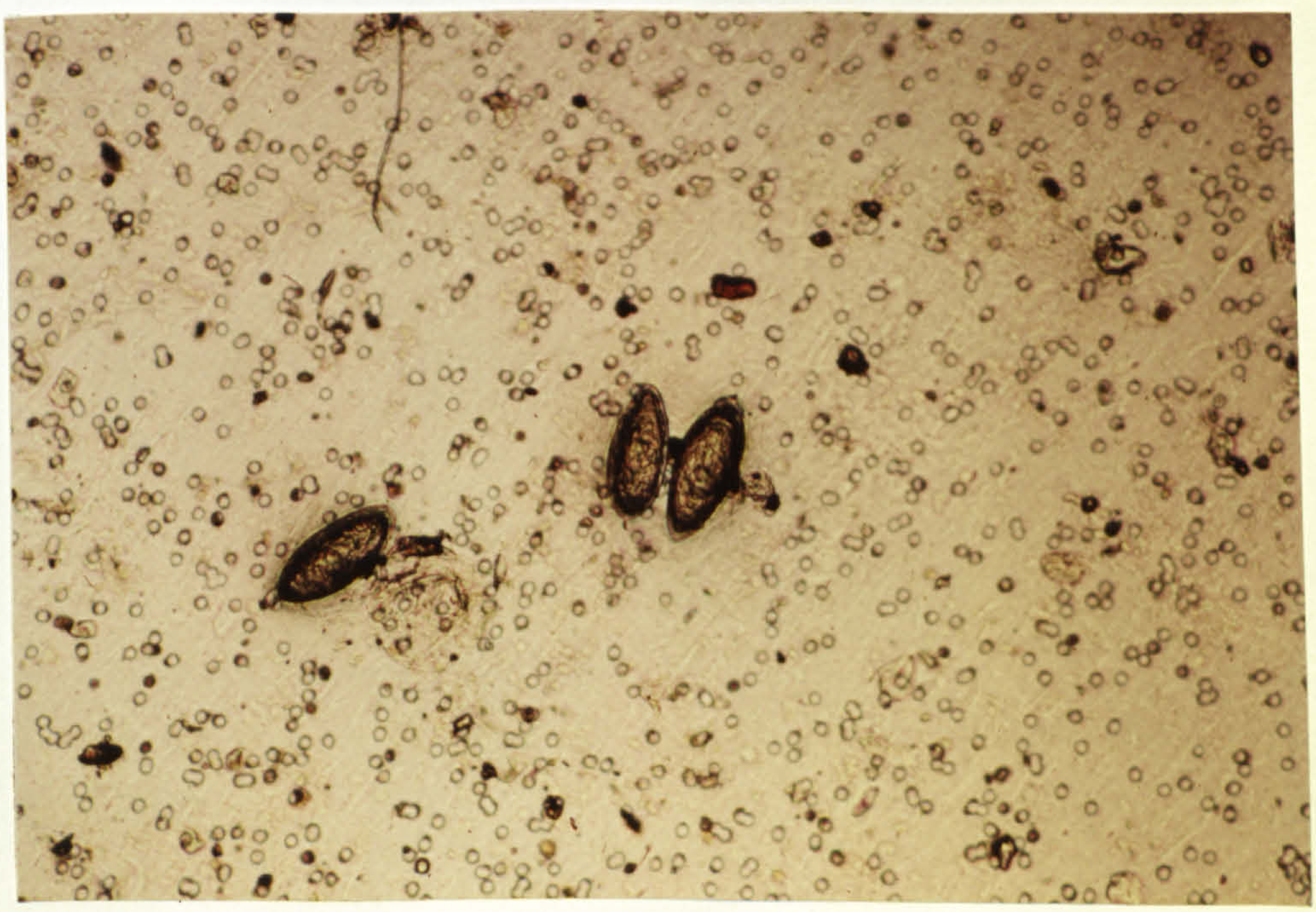


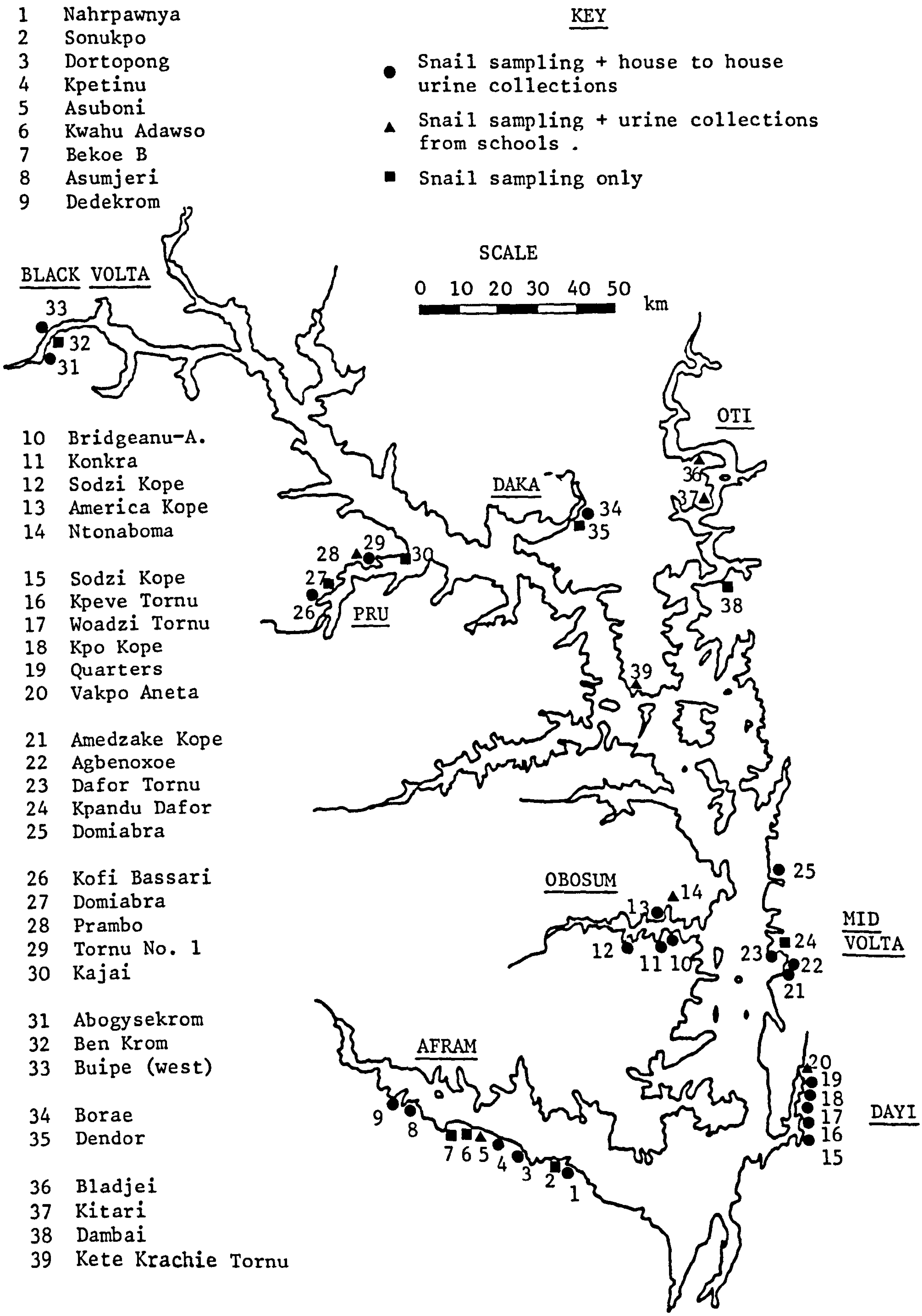
Plate 44. Three unstained S. haematobium eggs appearing clearly on Nuclepore filter (100 X) three weeks after eggs were first trapped on filter and kept unrefrigerated.

8.2.3 Degree of sampling of villages in the different lake sections

Map 13 shows which of the 39 villages selected for snail sampling were also sampled for human prevalence and intensity of *S. haematobium* infection. In 23 of the villages, urine was collected from all age groups, from house to house surveys. In 7 large communities, it was possible to collect urine only from a random sample of 5 - 19 year-old children, from primary and middle schools.

Urine collection and examination could not be carried out in the remaining 9 villages, due to lack of time and the onset of chemotherapy in 3 villages by the Ministry of Health.

Because of similar ecological conditions in the Afram and Obosum branches respectively, and the high percentage of total lakeside villages sampled in the Dayi section, the results on *S. haematobium* prevalence and egg counts from the 3 groups of villages were probably very representative of the overall status of *S. haematobium* infection throughout each respective lake section in 1979 and 1980. Results from the other lake branches were more sketchy, and cannot be viewed with as much confidence regarding the overall epidemiological picture in each respective branch.



Map 13

Location of the 39 study villages and type of sampling conducted in each.

8.2.4 Degree of coverage within sampled villages

Table 60 gives the fraction of compounds surveyed per village and the percentage of the village population from which urine was collected.

At Agbenoxoe, urine was collected from people in all 97 compounds in the village, in 2 prevalence/intensity surveys in 1979 and 1980. In this section, results from every third Agbenoxoe compound (house number 1, 4, 7, etc.) only are included, using the 1980 data. This follows the protocol for house to house sampling in a large lakeside village, and avoids giving the Agbenoxoe population too much weight in analyses involving data pooled from the different villages. This sample from Agbenoxoe gave results on age-specific prevalence rates and geometric mean of egg counts that were insignificantly different from results from all households.

For the villages where only school children were surveyed, Table 61 lists the fraction of schools sampled per total in the villages, and the number of children who provided urine.

Table 60. Number and percentage of people sampled in surveyed villages.

Village	Village population	No. of compounds surveyed per total in village	No. of people who: were registered	No. of people who: provided urine	% of people who provided urine, in regards to: no. registered	% of people who provided urine, in regards to: no. in village
AFRAM						
Nahrpawnya	122	15/15	122	96	79	79
Dortopong	94	13/13	70	62	89	66
Kpetinu	71	5/5	52	45	87	64
Asumjeri	85	8/8	70	59	84	69
Dedekrom	76	5/5	76	60	79	79
OBOSUM						
Bridgeanu-A.	349	57/57	349	214	61	61
Konkra	74	8/8	74	60	81	81
America Kope	25	4/4	25	18	72	72
Sodzi Kope	183	13/13	183	113	62	62
DAYI						
Dodzi Kope	104	15/17	104	78	75	75
Kpeve Tornu	141	19/19	141	85	60	60
Woadzi Tornu	72	6/6	72	49	68	68
Kpo Kope	49	7/7	49	39	80	80
Quarters	102	11/11	102	94	92	92
MID VOLTA						
Agbenoxoe	1086	31/97	380	387	76	26
Dafor Tornu	312	40/40	312	184	59	59
Amedzake Kope	75	5/5	75	65	87	87
Domiabra	195	27/27	195	150	77	77
BLACK VOLTA						
Buipe (west)	488[a]	28/50[a]	244	167	68	34[a]
Abogysekrom	106	8/8	106	68	64	64
PRU						
Kofi Bassari	578[a]	13/40[a]	231	165	71	29[a]
Tornu No. 1	304[a]	11/17	203	151	74	50
DAKA						
Borae	693[a]	19/57[a]	231	199	86	29[a]
Total	5384	368/529	3466	2508	72	47

a = estimate

Table 61. Number of children sampled in surveyed schools.

Village	Estimated population of village	Number of schools surveyed over total in village		Total number of children who produced urine
		Primary	Middle	
AFRAM				
Asuboni	450	1/1[a]	1/1[a]	67
OBOSUM				
Ntonaboma	1800	1/2	1/2	150
DAYI				
Vakpo Aneta	450	1/1	1/1	100
PRU				
Prambo	4000	1/?[b]	1/?[b]	150
OTI				
Bladjei	900	1/1	-	144
Kitari	800	1/1	-	102
Kete Krachie	5000	1/?[c]	1/?[c]	139
Total				852

[a] Schools about 2 km from Asuboni fishing village

[b,c] Exact number unknown (b = at least 2; c = at least 5).

8.3 RESULTS

8.3.1 Age and sex composition in the villages

Figure 27 shows these results from the 23 villages of house to house sampling.[1]

The apparent under-representation of the 15 - 19 year-old group was because many boys and girls were living away from the lakeside villages, attending boarding schools or learning trades.

The excess of females between 20 and 29 years of age was probably due to polygamy.

Below, the present results are summarized and grouped differently for older ages, so that they can be compared with unpublished WHO project data[2] on the population structure in the WHO study area in 1978.

Table 62. Percentage of registered population in different age groups.

Age group (years)	26 WHO study-unit villages, 1978	23 villages in different lake sections, 1979-80
0-4	13.0	17.5
5-9	18.2	19.3
10-14	15.0	16.3
15-24	16.0	17.2
25-34	13.5	11.9
35-44	11.4	8.1
45 +	12.9	9.7

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1 The total number of people in the age pyramid is 3135 - 335 less than the total number registered in Table 60. This is because some of the registered people were absent during visits by the team, and their age could not be determined.

2 From computer print-out sheets provided by WHO, Geneva.

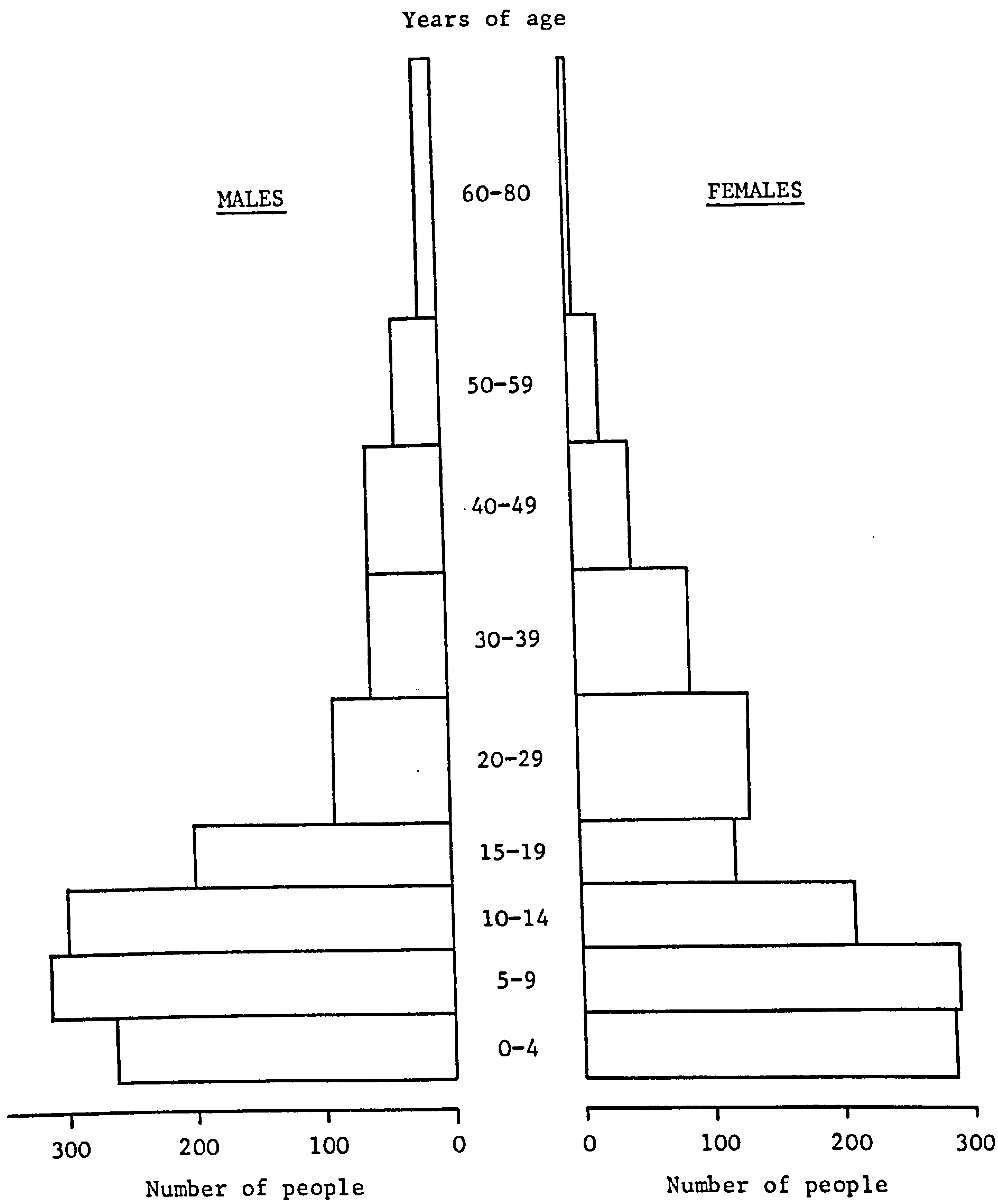

Fig. 27. Age pyramid of persons from sampling in 23 lakeside villages, where data on all ages of males and females were collected.

8.2.3 Overall age and sex-specific prevalence rates from sampled villages and schools

Table 63 shows the age-specific *S. haematobium* prevalence rates by sex for all people surveyed in the present study. The prevalence rate for all age groups was 64.7% for males and 53.3% for females, a significant difference. Prevalence rates were higher for males than females in every age group.

Compared to final precontrol results from the WHO study area (area of high endemicity), age-specific prevalence rates from the present survey were lower than in the Pawmpawm and Afram branches during 1975 (Scott et al., 1982). However, as in the WHO study area (and in most other endemic areas of *S. haematobium*), the increase and decline of prevalence rates with age showed the classic pattern: a rapid build-up of infection from the age of 5 - 14, maintenance of the peak to about age 19, then dropping rapidly among young adults, and remaining low and steady in older people.

Table 64 gives the age-specific geometric means of egg counts (per 10 ml) from all people that were positive for *S. haematobium*. As expected, values were greatest in the 5 - 19 year-old age span, peaking among 10 - 14 year-old males, and declining rapidly among young adults. Except for 30 - 39 year-olds, geometric means were much higher for males than females in every age group.

Table 63. Overall prevalence rates of S. haematobium in all villages and schools surveyed, by age and sex.

Age group	Number of people infected/ total number examined				Both sexes
	Males	%	Females	%	%
0-4	42/137	30.6	41/153	26.8	28.6
5-9	253/386	63.9	217/345	62.9	63.4
10-14	409/532	76.9	296/404	73.3	75.3
15-19	219/277	79.1	122/181	67.4	74.4
20-29	94/137	68.6	95/214	44.4	53.8
30-39	54/105	51.4	50/146	34.2	41.4
40-49	39/89	43.8	15/81	18.5	31.8
50-59	22/53	41.5	6/40	15.0	30.1
60 +	16/49	32.6	1/17	5.9	25.8
Total	1148/1775	64.7	843/1581	53.3	59.3

Table 64. Geometric mean of S. haematobium egg output per single 10 ml urine sample of all people found infected, by age and sex.

Age group	Males	Females	Both sexes
0-4	71	17	34
5-9	177	136	160
10-14	184	117	152
15-19	143	77	115
20-29	53	43	48
30-39	19	26	22
40-49	41	12	30
50-59	33	17	29
60 +	24	2	21
Total	122	80	101

8.3.3 Prevalence rate and geometric mean of positive egg counts by tribe

In the WHO project, people of the indigenous Krobo tribe, mainly farmers, had slightly higher overall prevalence rates of S. haematobium and geometric means of positive egg counts than the non-indigenous Ewe fisherfolk (Scott et al., 1982). Krobo children tended to gain the infection more rapidly than Ewe children, and then lose the infection more rapidly after the age of about 14. Among adults, levels of infection were slightly higher among Ewes, presumably, due to their greater water contact.

In the present study, urine was collected from 2113 Ewe people and 1243 people from several different tribes. Except for the oldest age groups which contained proportionately more Ewes in the population, the proportion of people in each age group of analysis was about equal for the 2 ethnic groupings. Figure 28 shows that there was not much difference between Ewes and other tribes as to S. haematobium prevalence rates and geometric means of positive egg counts. Values of both indices were highest for 5 - 14 year-old Ewes, but overall values were slightly lower for the Ewes due to greater numbers of Ewes over 30 years of age.

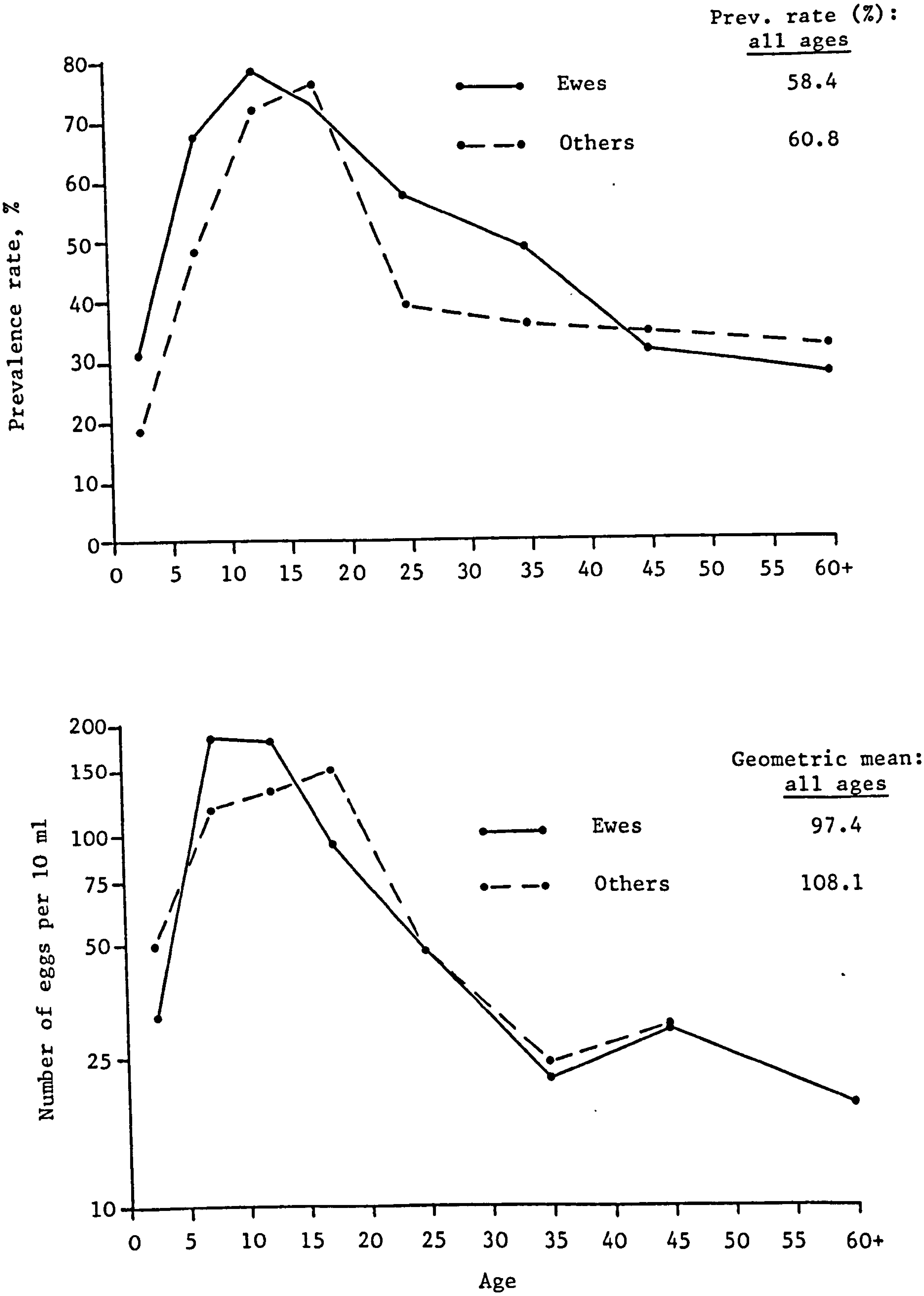

Fig. 28. Age-specific difference in prevalence rate of S. haematobium (top graph), and geometric mean of egg output in positive 10 ml urine samples (bottom graph) between Ewe people and people of other tribes.

8.3.4 Index of potential contamination

Using data on all screened individuals from the 23 villages where urine was collected from all age groups, practical information can be obtained on the importance of each age group in contaminating lake water with S. haematobium eggs.

In Table 65, an age-specific "index of potential contamination" was constructed by multiplying the proportion of each age group in the sample population with the respective, overall prevalence rate and arithmetic mean of egg counts per 10 ml. This follows the method of Jordan, Christie, and Unrau (1980) for S. mansoni in a St. Lucian population, which in turn, was a modification of earlier indices of this kind for S. japonicum in Leyte (Pesigan et al., 1958), and S. haematobium and S. mansoni in Egypt (Farooq and Samaan, 1967). The "relative index of potential contamination" for each age group was the I.P.C. expressed in relative percentage terms.

In the 23 Volta-Lake villages of analysis, 93% of the contamination potential was contributed by children aged 5 to 19, biggest contributors being 10 - 14 year-olds.

The importance of the 5 - 19 year-old age group is probably even more important in S. haematobium transmission than is indicated in Table 65. In Leyte (ibid), Egypt (ibid), and St. Lucia (Upatham, Sturrock, and Cook, 1976), hatchability of schistosome eggs was generally greater for children and lowest for adults. In Ghana, Dalton and Pole (1978) found that water contact was most frequent and long-lasting among 5 - 14 year-olds, and at Agbenoxoe (chapter 9, this thesis), it was most intense among 10 - 19 year-olds.

The present finding of greatest transmission potential in the 5 - 19 age-span adds support to the concept of "targeted mass chemotherapy" for achieving cost/effective control of S. haematobium in endemic areas, although not necessarily according to the strategy of Warren and Mahmoud (1976), who recommended concentrating chemotherapy on heaviest egg excretors only, regardless of age.

Around the Volta Lake, a chemotherapy campaign would seem to be most cost/effective if it concentrated drug delivery on the 5 - 19 year-old population, regardless of variation in intensity of infection between positive individuals.

Table 65. Relative index of potential contamination of S. haematobium eggs by different age groups, from total house to house sampling results in 23 villages.

Age group	Population structure per 100 people (1)	Prevalence rate in % (2)	Arithmetic mean egg count (3)	Index of potential contamination (1 x 2/100 x 3)	Relative I.P.C. in %
0-4	17.5	28.6	65.6	328	1.4
5-9	19.3	65.5	621.7	7859	34.1
10-14	16.3	79.6	813.0	10549	45.8
15-19	10.1	72.8	406.4	2988	13.0
20-29	14.3	53.8	120.6	928	4.0
30-39	9.5	41.4	53.7	211	0.9
40-49	6.6	31.8	42.3	89	0.4
50-59	3.9	30.1	53.0	62	0.3
60 +	2.5	25.8	12.0	8	0.1
Total	100.0	56.0	365.5	23022	100.0%

8.3.5 Prevalence rates and geometric means of egg counts by narrow age grouping

Of the 2508 urine samples collected in the 23 villages where all age groups were examined, data on age to the nearest year were recorded from 2169 people (86.5%). Most children between 9 and 19 years old seemed to know their age to within one year, and if in doubt, it could be obtained from parents or relatives. But there was still some guesswork involved.[3] Among younger children, age was mainly assessed from questioning parents, as well as by physical appraisal. Of the adults, people over 40 tended to exaggerate their age, and in these cases, an educated guess was made, mainly on the basis of physical appearance.

In the analysis that follows in this section, data from the 23 villages are presented on prevalence rates and geometric means of egg counts by 1-year intervals of age from 0 to 19, 5-year intervals from age 20 to 49, and 10-year groupings from age 50 to 79.

There is bound to be some error in the accuracy of ages as presented, especially yearly age assessment between 9 and 19. But with the large number of people examined in most of the age categories, the recorded ages are probably sufficiently accurate for the observed epidemiological results to be viewed with confidence.

Table 66 gives details of the results for the narrow age breakdown, including prevalence rates, arithmetic means of egg counts, mean logs of all egg counts plus 1 (to accomodate negatives), and standard deviations of the counts. The index of potential contamination among 0 - 19 year-olds by 1-year age grouping is shown in Table 67.

The age-specific prevalence rates and mean logs from Table 66 appear as fairly smooth curves in Figure 29. The prevalence rate is expressed as the percentage found negative on a logarithmic scale, which is also used to depict the mean log counts of eggs plus 1.

---

[3] Educational standards in Ghana have traditionally been the highest in West Africa, and even in fishing villages, the majority of children attend at least primary school. People without any education are becoming increasingly age-conscious due to increasing bureaucratic encroachment in their lives; e.g., registration at hospitals and clinics, voting, identity cards, drivers' licenses, etc.

Table 66. Age-specific prevalence rates, means, and other measures of egg output (per 10 ml) from sampled villages around the Volta Lake, including participants for whom age could be most accurately determined.

Age group (years)	No. examined	% passing eggs	Mean egg output	S.D. of egg output	Mean log of egg output (eggs + 1)	S.D. of log egg output
0	4	0	0	0	0	0
1	28	21.4	2.2	7.8	0.177	0.398
2	47	27.7	75.1	291.5	0.384	0.842
3	80	20.0	48.0	184.3	0.391	0.846
4	103	33.0	94.7	491.0	0.531	0.906
5	79	45.6	316.6	866.0	0.956	1.236
6	108	60.2	380.7	1059.0	1.271	1.248
7	102	60.8	639.9	1098.9	1.587	1.411
8	88	72.7	1060.2	3182.3	1.701	1.364
9	96	79.2	719.3	1405.4	1.934	1.210
10	100	83.0	809.2	1532.7	1.995	1.177
11	84	79.8	742.8	1377.1	1.933	1.201
12	80	70.2	565.1	1162.3	1.675	1.241
13	78	78.2	923.7	2040.2	1.831	1.271
14	66	78.8	972.9	1860.4	1.948	1.272
15	70	80.0	477.7	1703.6	1.733	1.105
16	55	80.0	478.9	1112.4	1.674	1.197
17	42	71.4	502.5	1413.3	1.582	1.228
18	50	58.0	165.4	368.9	1.175	1.180
19	39	69.2	339.5	695.5	1.441	1.203
20-24	153	61.4	141.2	595.5	1.086	1.036
25-29	136	55.1	109.6	371.6	0.905	0.990
30-34	86	45.3	30.3	78.2	0.622	0.829
35-39	115	44.3	48.2	161.0	0.609	0.871
40-44	69	33.3	22.4	59.5	0.513	0.805
45-49	59	30.5	78.1	309.4	0.475	0.882
50-59	89	30.3	55.2	332.0	0.461	0.818
60-69	49	28.6	14.5	41.5	0.385	0.696
70-79	14	14.3	4.1	11.4	0.206	0.529

Table 67. Relative index of potential contamination of S. haematobium eggs by yearly age grouping in the 0 - 19 year-old, sampled population in 22 villages.[a]

Age group	Population structure per 100 people (1)	Prev. rate in % (2)	Arithmetic mean egg count (3)	Index of potential contamination (1 x 2/100 x 3)	Relative I.P.C. in %
0	3.2	0	0	0	0
1	5.5	21.4	2.2	2.6	0
2	5.0	27.7	75.1	104.0	0.3
3	7.0	20.0	48.0	67.2	0.2
4	7.3	33.0	94.7	288.1	0.7
5	5.5	45.6	316.6	794.0	2.3
6	6.9	60.2	380.7	1581.4	4.7
7	6.3	60.8	639.9	2451.1	7.3
8	5.5	72.7	1060.2	4239.2	12.6
9	6.1	79.2	719.3	3475.1	10.3
10	6.3	83.0	809.2	4231.3	12.6
11	5.0	79.8	742.8	2963.8	8.8
12	5.0	73.8	565.1	2085.2	6.2
13	4.7	78.2	923.7	3395.0	10.1
14	4.2	78.8	972.9	3219.9	9.6
15	4.6	80.0	477.7	1757.9	5.2
16	3.3	80.0	478.9	1264.3	3.7
17	2.6	71.4	502.5	932.8	2.8
18	3.2	58.0	165.4	307.0	0.9
19	2.6	69.2	339.5	610.8	1.8
Total	100.0	62.9	527.6	33710.7	100.0

[a] Data on yearly ages for 0 - 19 year-olds not available from Nahrpawnya.

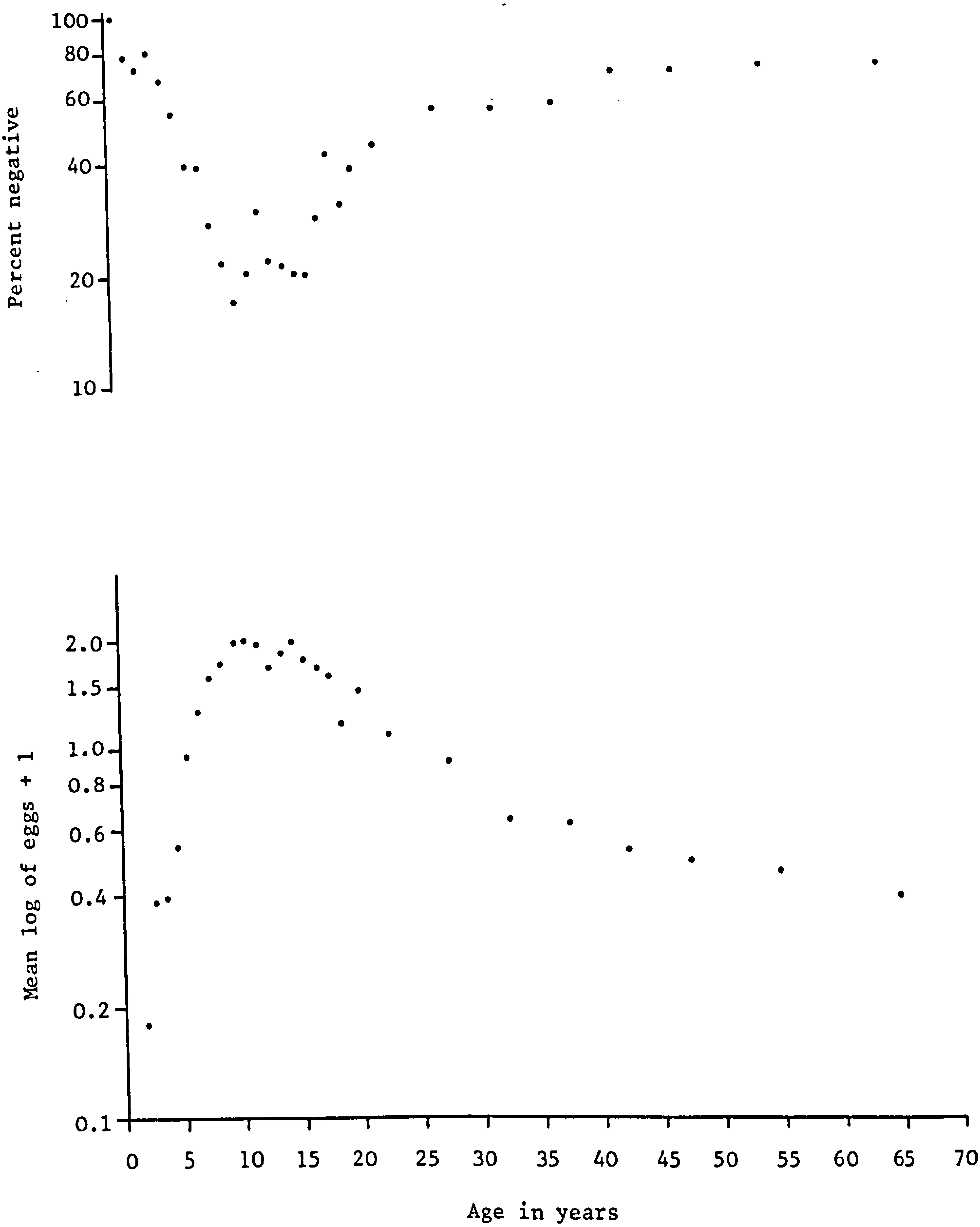

Fig. 29. Age-specific prevalence rates of S. haematobium (% negative), and mean logs of egg output (eggs + 1 per 10 ml urine) of 2169 people surveyed around the Volta Lake, for whom age could be most accurately determined.

Both curves in Figure 29 agree in basic shape with the first detailed analysis of this kind on S. haematobium in Africa - that by Bradley and McCullough (1973) at Misungwi, Tanzania.

In Ghana, there was a clear exponential decrease in the proportion of people found negative, with increasing age, from 3 - 10 years. In the same age span, there was an exponential increase in the mean log number of eggs. Between 11 and 16 years of age, prevalence rates decreased only a little, and irregularly, and there was no clear trend of a drop-off in the mean log of egg counts until after age 14. The decline in prevalence rates and egg counts continued at a steady, exponential rate until about age 30, before tapering-off gradually among older people.

Bradley and McCullough (ibid) attributed the 3 main phases of the rise and fall of prevalence rates and egg counts at Misungwi to the development, effect, and gradual loss of "concomitant immunity" - or protection against new infections in already-infected persons.

Jordan, Cook, and Davis (1974) criticized aspects of this model, and implied selective use of data available to McCullough and Bradley (1973), and Bradley and McCullough (ibid). Jordan et al.(ibid) argued that superinfection was a phenomenon that continued to occur in 10 - 14 year-old children, and even in some older children. Bradley and McCullough (ibid) stated that 10 - 14 year-olds are "both heavily infected and protected against further infection".

Wilkins and Scott (1978) acquired evidence in the Gambia to show that year to year stability of group mean egg counts in heavily infected children was actually the result of a dynamic equilibrium, where "worms" were rapidly lost after the main transmission season and then replaced as superinfection occurred during the following transmission season. The greatest degree of superinfection occurred in infected children between the ages of 6 and 10, although some superinfection was evident in teen-agers as well. Wilkins and Scott (ibid) concluded that although some type of concomitant immunity builds up in infected children, another immune response seems to develop in older children and adults which affects "the egg-laying worms of the established infection". They also mentioned that reduced water contact by older children and adults could be an important factor in lower levels of infection among adults.

Since the Volta Lake had been in existence only for 15 years at the time of data collection in the present study, the tail-off in prevalence rates and egg counts in people above 30 years of age was likely much more a consequence of reduced water contact than a state reached by progressive dying-off of worms from a previous condition of heavy or moderately-intense infection.

One of the basic assumptions in Bradley and McCullough's (ibid) analysis of observed age-specific prevalence rates and egg counts (shown for the present study in Figure 29) was that the epidemiological situation at Misungwi had remained stable for many years. But the present findings from the Volta Lake show that almost identical curves can result from the same parameters even though this basic assumption is not met.

8.3.6 Applying catalytic models to the age-specific prevalence rates to estimate incidence rates and rates of loss of infection

The prevalence-rate results from the narrow age grouping can be used to make realistic estimates of the overall, annual incidence rates and rates of annual loss of infection ("outcidence" rates) that occurred in the 23 villages during 1979 - 1980.

To do this, catalytic curves can be fitted to the observed results. Hairston (1965) first demonstrated this technique for human schistosomiasis, which was based on the original description of catalytic model application to human infections in general by Muench (1959).

Hairston (ibid) pointed out that the most fundamental assumption in applying catalytic curves to age-prevalence data is that the "epidemiological situation has remained the same for the length of the life of the oldest age-group considered . . ." Because the Volta Lake was only 15 years old during the present surveys, this limited consideration of age to children no older than 15. But in the analysis that follows, calculations had to be extended to include 16, 17, 18, and 19 year-olds as well, for the 2-stage catalytic curve to be mathematically applicable.

The basic equation of the 2-stage catalytic model devised by Muench is:

$$y = a/(a - b)\ (e^{-bt} - e^{-at})$$

where " a is the instantaneous rate of becoming positive per year; b is the instantaneous rate of becoming negative per year; e is the base of natural logarithms; t is time in years; and y is the expected proportion positive" (Hairston, ibid).

The constants a and b can be calculated from the observed age-prevalence data following the instructions of Muench (ibid), and using his provided nomogram.

Hairston found that applying just one 2-stage catalytic model to the observed age-specific data on human schistosomiasis would not normally result in a good fit. This was because children from 0 to about 5 years of age seem to be subjected to a lower "force" of infection than older children (presumably due to less water contact). Hairston demonstrated that for S. haematobium, S. mansoni, and S. japonicum, 2 separate (2-stage) catalytic curves should be fitted to the observed data - one for the younger children, a second for the rest of the population considered. This resulted in good fits of the models for varying age-prevalence results involving all 3 schistosome species. The corrections needed to calculate and fit the second curve so that it begins close to where the first curve ends were admirably described by Hairston (ibid).

In Figure 30, Hairston's method has been followed to fit 2 separate catalytic models to the observed age-prevalence results from the Volta Lake (taken from Table 66). It can be seen that excellent fits were obtained for both age divisions. The second curve even fitted observed results in adults up to 30 years of age, even though, in reality, people close to 30 years old in 1980 were probably never exposed to the same force of infection as the present 5 - 19 year-old group from which the curve was calculated.

Bradley and McCullough's model (1973) for S. haematobium at Misungwi assumed that the force of infection remained constant for children progressing from 2 to 11 years old. The present results, and the analysis by Hairston (ibid) suggest that this is not always true.

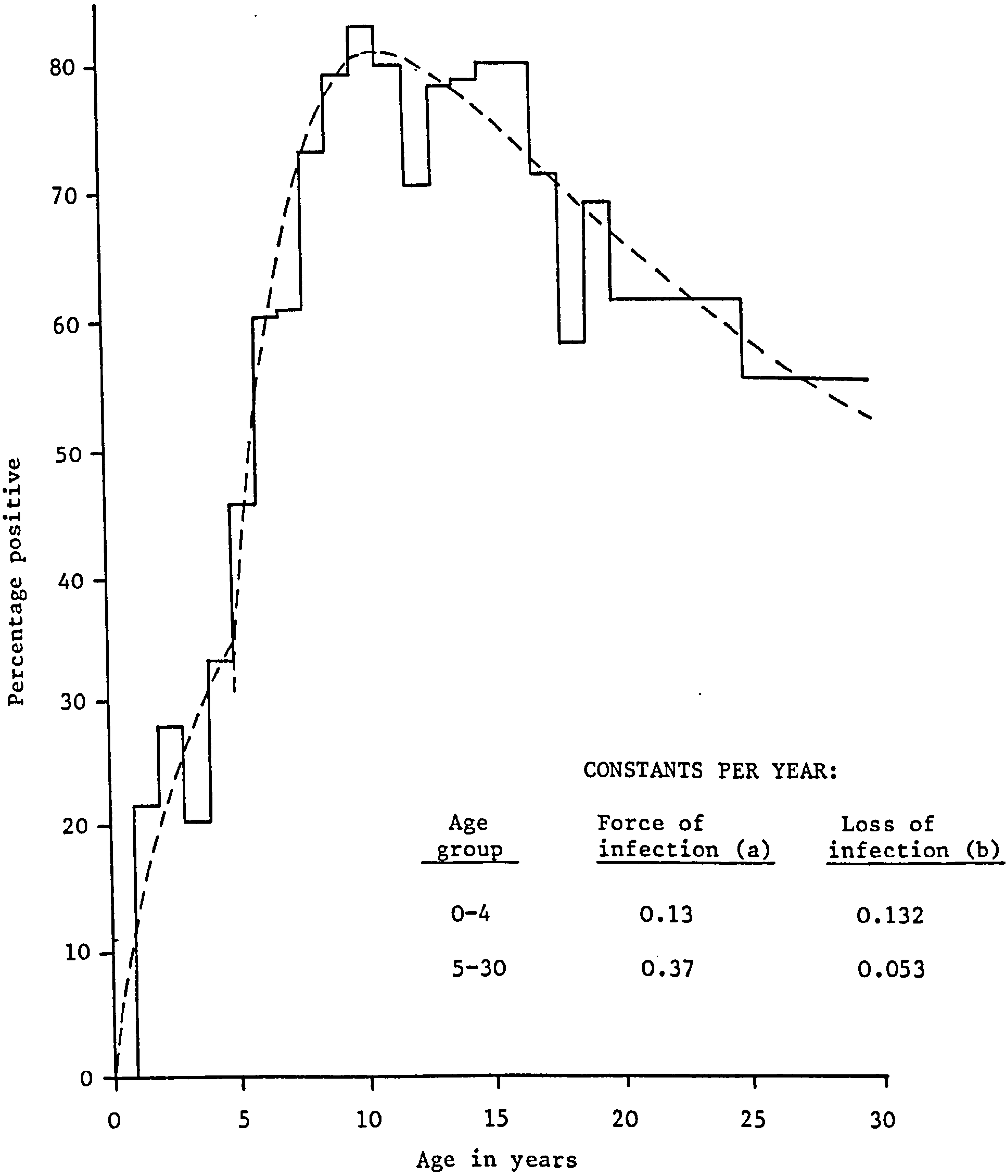

Fig. 30. Observed age-specific prevalence rates of S. haematobium from 23 villages around the Volta Lake, with curves calculated on the basis of separate catalytic models for two age divisions, with the second curve corrected to begin at a prevalence rate of 30 %.

The real value of the 2 catalytic curves in the present study is to allow estimates to be made of the true annual incidence rates that existed in those portions of the lake surveyed. To convert the instantaneous force for infection (a) to the annual incidence rate, and the instantaneous loss of infection (b) to the annual loss of infection ("outcidence" rate), the following conversions must be made:

$$\text{annual incidence rate (i)} = 1 - e^{-a}$$

$$\text{annual "outcidence" rate (o)} = 1 - e^{-b} .$$

Thus, among the 0 - 4 year-olds, the prediction of the annual incidence rate is 12.1%, and the predicted annual "outcidence" rate is 12.4%. Among the 5 - 19 year-old age group, the expected annual incidence rate is 30.9%, and the expected annual "outcidence" rate is 5.2%.

8.3.7 Findings on prevalence rates and egg counts in individual villages and different sections of the lake

Age-specific prevalence rates and geometric means of positive egg output are listed for all 30 villages surveyed, in Tables 68 and 69 respectively.

Among 5 - 19 year-olds in the Afram and Obosum branches, prevalence rates were over 85%, and geometric means of egg counts (per 10 ml) over 250, in every surveyed village except for the Asuboni school children.

In the Dayi and Mid Volta sections, overall prevalence rates for all people surveyed was 55.1% and 53.4% respectively; overall geometric means of egg counts were 46 and 90. The tables show levels of infection much more focally determined there than in the Afram and Obosum branches.

The high prevalence rates and egg counts at Amedzake Kope were primarily due to very heavy human water contact. The low overall prevalence rate at Agbenoxoe was a consequence of little water contact by adults. Despite the absence of observed local transmission at Dafor Tornu, infection among most residents seems to have been imported, following frequent fishing trips to other parts of the lake.

Table 68. S. haematobium prevalence rates in all sampled villages, by age.

Village	0-4	5-9	10-14	15-19	20-29	30-39	40-49	50+	Total %	
Nahrpawnya*	1/7	20/25	21/24	2/2	7/12	7/11	6/11	2/4	68.8	Afram
Dortopong*	9/14	9/9	6/7	9/9	15/17	3/3	1/1	2/2	87.1	
Kpetinu*	0/2	9/11	5/5	8/8	8/9	5/7	0/1	1/2	80.0	
Asumjeri*	1/9	11/14	8/9	4/4	7/11	4/7	3/4	1/1	66.1	
Dedekrom*	2/7	14/15	4/4	9/11	5/7	7/8	1/5	1/3	71.7	
Asuboni*		20/26	22/30	8/11					74.6	
Total %	33.3	83.0	83.5	88.9	75.0	72.2	50.0			
Bridge.-A.*	4/17	40/45	57/59	17/20	8/13	9/20	5/17	11/23	70.6	Obosum
Konkra*	8/8	14/15	15/15	4/5	9/9	3/3	3/3	2/2	96.7	
Sodzi K.*	11/13	25/28	20/21	13/13	16/19	11/15	3/4		87.6	
Amer. K.	0/1	1/1	4/4	2/2	1/3	2/2	1/1	4/4	83.3	
Ntonaboma		34/40	67/68	41/42					94.7	
Total %	59.0	88.4	97.6	93.8	77.3	62.5	48.0	58.6		
Sodzi Kope*	5/10	10/11	10/13	9/14	3/7	5/9	4/4	3/5	62.8	Dayi
Kpeve T.	2/8	13/26	10/10	6/7	4/8	0/7	0/6	1/12	42.4	
Woadzi T.	0/7	0/8	5/10	3/8	1/2	0/4	0/3	0/4	18.4	
Kpo Kope	5/9	8/8	5/5	3/3	4/4	1/2	0/3	1/5	69.2	
Quarters	6/19	20/21	9/11	10/13	11/15	2/4	4/7	4/4	70.2	
Vakpo A.		6/12	29/49	23/39					58.0	
Total %	34.0	66.3	69.4	64.3	63.9	30.7	28.6	30.0		
Agbenoxoe*	1/27	23/54	38/52	33/48	6/23	4/23	1/22	3/38	38.0	Mid Volta
Dafor T.	2/20	28/45	31/35	16/21	15/34	5/16	1/7	2/6	54.3	
Amed. Kope*	8/12	12/13	13/13	8/8	6/7	6/7	4/5	1/1	89.2	
Domiabra	5/14	26/32	28/29	17/18	11/15	2/4	4/7	4/4	70.2	
Total %	21.6	62.2	85.3	77.9	48.1	35.6	19.1	15.0		
Buipe (West)	8/24	25/31	19/19	12/13	22/32	15/32	8/14	1/2	65.9	Northern sections
Abogyse.	3/12	9/16	12/15	4/4	5/11	2/5	2/4	0/1	55.2	
Kofi Bas.*	0/9	18/41	21/32	5/8	19/40	4/15	1/12	1/8	40.8	
Tornu 1*	1/8	13/22	27/43	9/24	4/22	2/18	2/7	1/7	39.1	
Prambo		17/28	59/82	30/40					70.7	
Bladjei*		29/44	78/91	9/9					80.6	
Kitari		7/30	25/65	4/7					35.3	
K. Krachie		7/27	51/81	23/31					58.3	
Borae	1/32	2/44	6/35	0/16	2/31	1/20	1/11	0/10	6.6	
Total %	15.3	44.9	64.4	63.1	38.2	26.7	29.2	10.7		

* = villages with Ceratophyllum

Table 69. Geometric mean of egg output (per 10 ml) among all people found infected, by age.

Village	0-4	5-9	10-14	15-19	20-29	30-39	40+	Total
Nahrpawnya	17	133	759	248	183	22	33	165
Dortopong	63	1085	1105	633	136	147	49	262
Kpetinu		766	171	334	125	59	2	205
Asumjeri	6	101	309	311	121	32	42	111
Dedekrom	93	508	881	144	101	48	27	187
Asuboni*		183	77	57				103
Total	50	264	296	219	133	43	31	103
Bridg.-A.	114	472	503	201	32	20	66	245
Konkra	61	1307	1038	624	29	37	5	218
Sodzi K.	219	440	383	79	50	36	54	155
America K.*		209	419	989	13	15	29	98
Ntonaboma		201	589	316				380
Total	125	405	553	242	37	28	36	
Sodzi Kope	25	64	156	33	15	26	5	36
Kpeve T.*	11	34	34	29	9		25	27
Woadzi T.			7	27	4			10
Kpo Kope	31	64	45	56	26	7	55	42
Quarters	18	59	90	240	93	35	32	68
Vakpo Aneta		119	90	21				63
Total	22	58	67	49	34	18	14	
Agbenoxoe	2	64	230	97	21	4	19	89
Dafor Tornu*	1	88	142	49	44	5	108	67
Amedzake Kope	7	1200	441	138	89	15	173	141
Domiabra	91	339	107	60	43	17	11	91
Total	12	170	177	78	44	9	39	
Buipe (West)	32	279	401	599	65	28	21	125
Abogysekrom	7	165	234	148	16	12	41	82
Kofi Bassari		109	121	111	20	4	7	54
Tornu No. 1*	3	177	67	29	10	2	14	50
Prambo		20	99	84				73
Bladjei*		71	51	55				56
Kitari*		8	47	34				32
Kete Krachie		7	44	119				50
Borae*	28	35	59		14			42
Total	18	75	75	102	30	17	16	

* = shores unprotected against wave action.

In the northern, savannah sections, observed levels of S. haematobium infection were generally in the same range as sampled villages in the Dayi and Mid Volta sections. The one village with an extremely low level of infection was Borae in the Daka branch. As mentioned, Jones (1973) found that the indigenous population throughout the Daka branch was free of S. haematobium. Highest prevalence rates and egg counts in the northern sectors were at Buipe. This was presumably due to heavy water contact in WCPs that were ecologically favourable for intense transmission.

Data from Tables 68 and 69 have been combined in such a way to show area-wide prevalence rates of S. haematobium and geometric means of egg output respectively, in 3 major, ecologically distinct sections of the lake: (1) the Obosum and Afram branches; (2) the Dayi and Mid Volta branches; and (3) the northern branches (Figure 31). These results were not standardized for age and sex - this would have made little difference to the results as presented. Superimposed on each respective graph are the unstandardized results from the final survey in the WHO study area in 1975 (Scott et al., 1982), with the geometric means of positive egg counts corrected to represent 10 ml urine samples.

Figure 31 clearly shows how much higher prevalence rates and egg counts were in the Afram-Obosum villages compared to the other lake sections. The large number of negative people at Borae depressed the overall results for the northern sections. But because many unsampled villages in the northern branches are like Borae in ecology, it is reasonable to assume that prevalence rates of S. haematobium are generally lowest in the northern parts of the lake.

Prevalence results from the WHO project were almost identical with the present findings in the Afram-Obosum villages, although egg counts were slightly lower in the WHO study area.

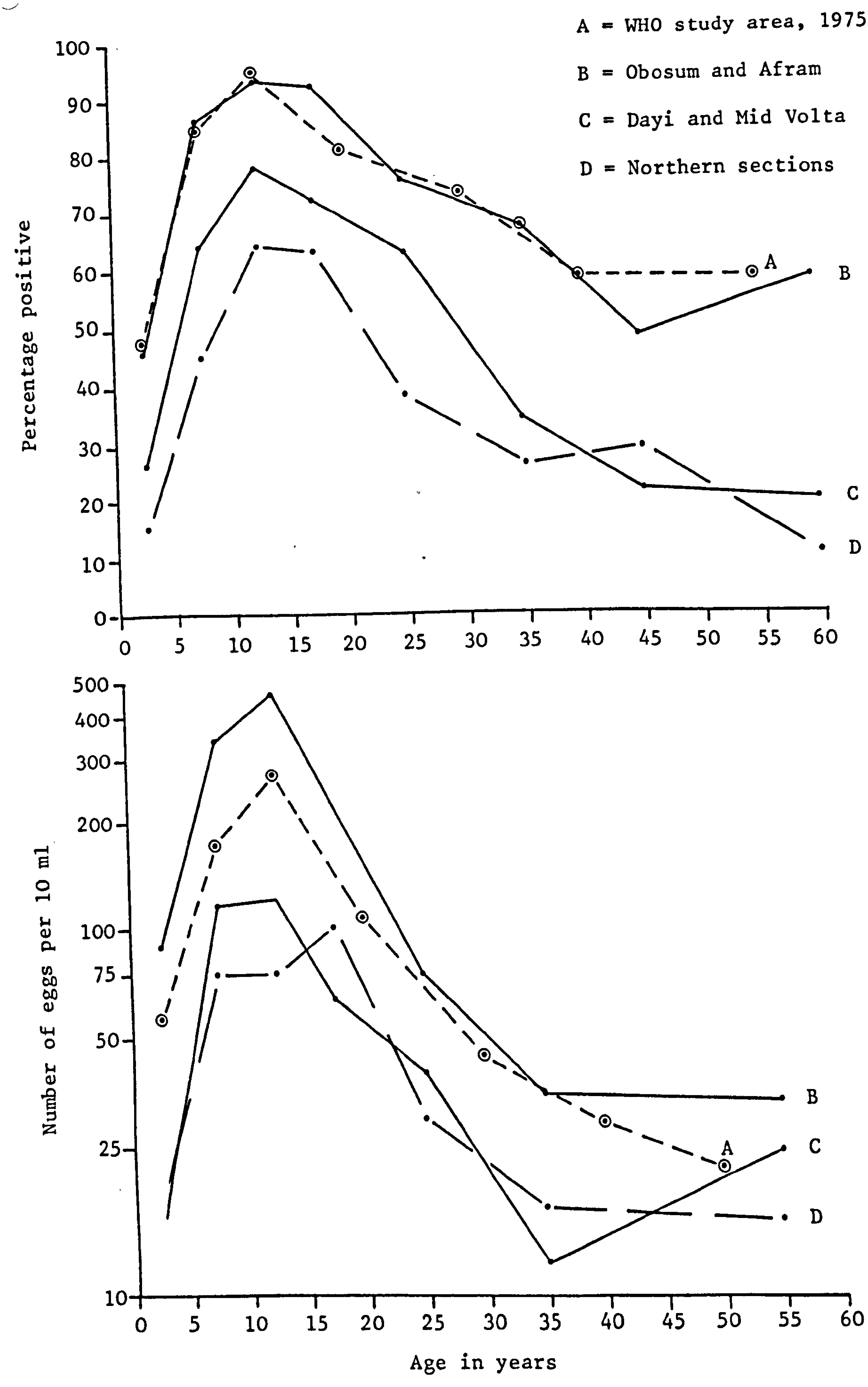

Fig. 31. Age-specific prevalence rates of S. haematobium (top graph), and geometric means of egg output in positive 10 ml samples (bottom graph) in different sections of the lake.

8.3.8 Applying catalytic models to the age-prevalence results in the Obosum branch

Because prevalence rates and egg counts were so high in all 5 sampled villages in the Obosum branch, it would be of value to examine in some detail the dynamics of transmission in this lake section.

In Figure 32, age-prevalence rates have been plotted for all of the children examined in the 5 Obosum-branch villages who were between the ages of 0 and 19. The results from the Ntonaboma schools were used because not only were accurate records kept on students' age, but age proportions and prevalence rates from the 2 schools were also comparable with the other 4 villages. Since the prevalence rates for all children examined between age 8 and 16 were close to 100%, any error on exact age determination in this age span would be inconsequential.

As can be seen from the graph, the first catalytic model included children from 0 - 5 years of age, while the rest were covered by the second curve. Both models produced reasonably good fits. The worst fit was for the 9 to 17 age span. One weakness of a catalytic model with a high "a" value is that as soon as "t" increases slightly, e^{-at} becomes negligable and the curve "y" starts to descend at a rate determined by e^{-bt}. The observed prevalence rates of 94 - 100% among the 9 - 17 year-olds imply that any loss of infection until 17 years of age was only temporary, and also suggest a degree of superinfection occurring.

Using the formula to convert the constants "a" and "b" into annual incidence and "outcidence" rates, the predicted incidence rate among the 0 - 5 year-old group comes to 23.7% per year. This is almost double the predicted rate among 0 - 4 year-olds in the 23 villages as a whole. The annual "outcidence" rate among the "Obosum" group was 4.1%, and this was only one-third as high as in the 23 villages combined.

Among the 6 - 19 year-old group in the Obosum branch, the estimated force of infection of 1.80 converts into a 83.5% annual incidence rate. While this was 2.7 times higher than the predicted rate for 5 - 19 year-olds in all 23 villages, it is similar to the 100% "crude incidence" rate recorded among a very small group of 10 - 14 year-olds in the high transmission (Afram) villages in the WHO study area that occurred between 1973 and 1975 (final UNDP/WHO report, 1979).

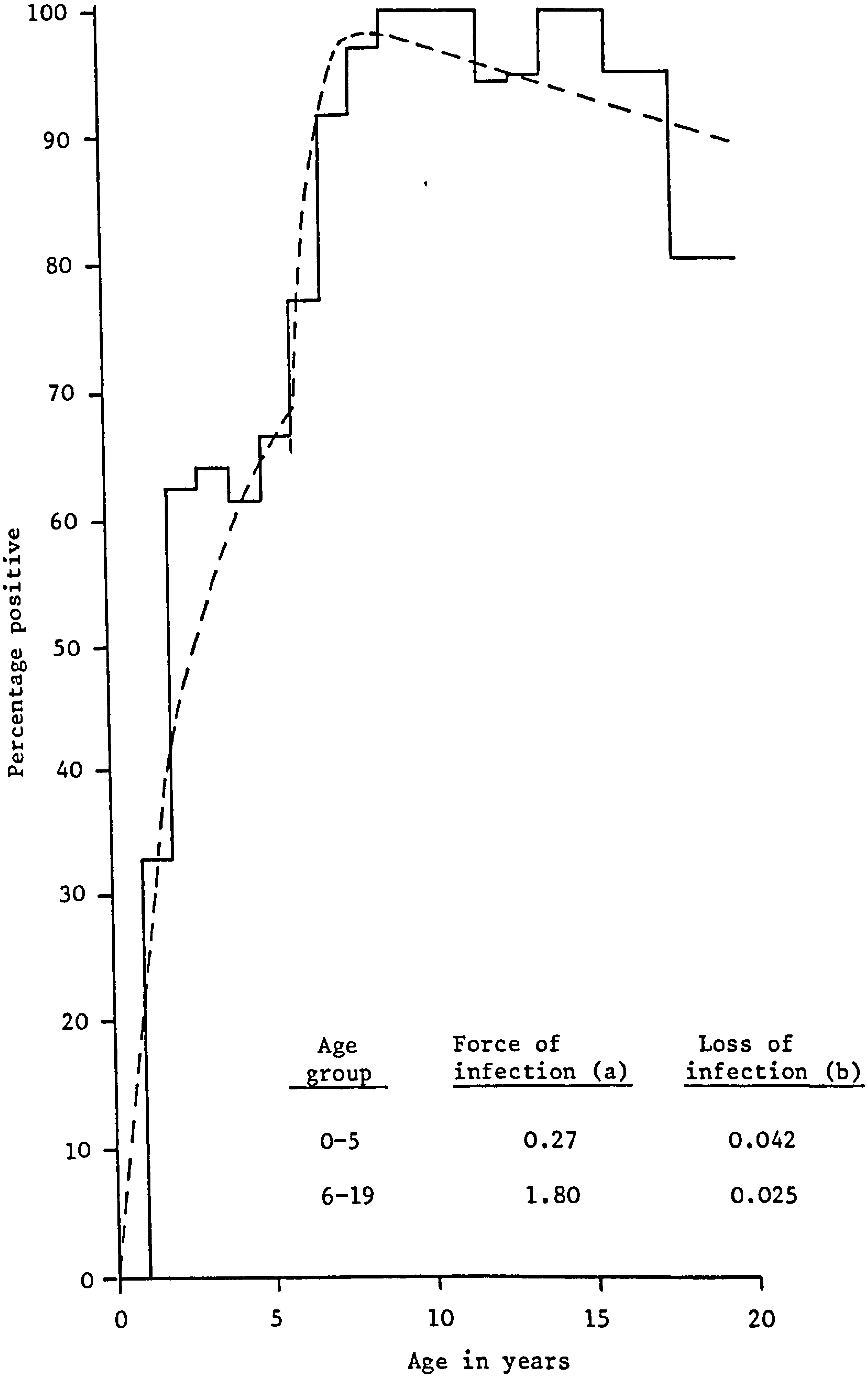

Figure 32. Observed age-specific prevalence rates of S. haematobium from five Obosum-branch villages, with curves calculated on the basis of separate catalytic models for two age divisions, and with the second curve corrected to begin at a prevalence rate of 65%.

The calculated "outcidence" rate among the older "Obosum" children is only 2.5% per year - one-half the figure from all 23 villages.

8.3.9 Evidence of an increase in S. haematobium prevalence around the Volta Lake since 1972

The first assessment of the distribution of *S. haematobium* around the lake was made between 1970 and 1972 by the Volta Lake Research Project. Urine samples were collected from 5 - 14 year-old children in more than 140 lakeside villages (see chapter 2). In the present survey, 15 lakeside villages that were originally studied by the VLRP were also sampled by the author.

In Table 70, the 2 sets of results from the 15 villages are compared on the prevalence-rate findings among 5 - 14 year-olds.

Between the time of the VLRP survey and the present sampling, prevalence rates increased significantly in 9 of the 15 villages, and increased insignificantly in 3 others. Prevalence rates decreased in only 3 villages, and these drops were insignificant.

The biggest increases were at Kofi Bassari and Prambo in the Pru branch. The present snail sampling results indicate that levels of *S. haematobium* infection in these 2 villages are likely to increase further.

The *Ceratophyllum* infestation in the Obosum branch after 1973 was probably the main factor in the big increase in prevalence rates noted at Konkra, Ntonaboma, and Sodzi Kope.

Table 70. Volta-Lake villages surveyed for S. haematobium prevalence among 5 - 14 year-old children by the VLRP between 1970 - 1972, and surveyed again in the present study between 1979 - 1980, with prevalence rates also restricted to 5 - 14 year-old children.

Lake branch village	No. positive / No. examined				Increase (+) or decrease (-)	Signif. of χ^2 test at 95% level
	1970-1972	(%)	1979-1980	(%)		
Afram						
Nahrpawnya	47/53	88.7	41/49	83.7	-	NS
Asuboni	73/82[a]	89.0	42/56[a]	75.0	-	NS
Obosum						
Konkra	11/26	42.3	29/30	96.7	+	S
Ntonaboma	70/95	73.7	101/108	93.5	+	S
Sodzi Kope	9/19	47.4	45/49	91.8	+	S
Dayi						
Woadzi Tornu	10/34	29.4	5/18	27.8	-	NS
Quarters	26/48	54.2	29/32	90.6	+	S
Mid-Volta						
Agbenoxoe	57/227	25.1	61/106	57.5	+	S
Domiabra	27/44	61.4	54/61	88.5	+	S
Pru						
Kofi Bassari	5/55	9.1	39/73	53.4	+	S
Prambo	3/78	3.8	76/110	69.1	+	S
Oti						
Bladjei	49/122	40.2	107/135	79.2	+	S
Kitari	26/99	26.3	32/95	33.7	+	NS
Kete Krachie	147/344	42.7	58/108	53.7	+	NS
Daka						
Borae	4/96	4.2	8/79	10.1	+	NS

S = significant difference; NS = not significant.

[a] VLRP sampling at Asuboni fishing village; present sampling at Asuboni school.

8.3.10 Some ecological factors influencing prevalence rates and intensity of S. haematobium infection around the lake

Ceratophyllum

Figure 33 illustrates the difference in age-specific prevalence rates and geometric means of egg output among positives, between 16 surveyed villages where Ceratophyllum infestation was observed during snail sampling, and in 14 villages where the weed was absent, or only occasionally present as tiny fragments. (See Table 68 for the breakdown.)

Prevalence rates and geometric means were significantly higher in the villages where the weed grew than in the villages where it was not observed.

The data give further evidence that the very presence of established Ceratophyllum in the littoral zone of a lakeside village is a key indicator to predict high transmission and high intensity of S. haematobium infection among the residents.

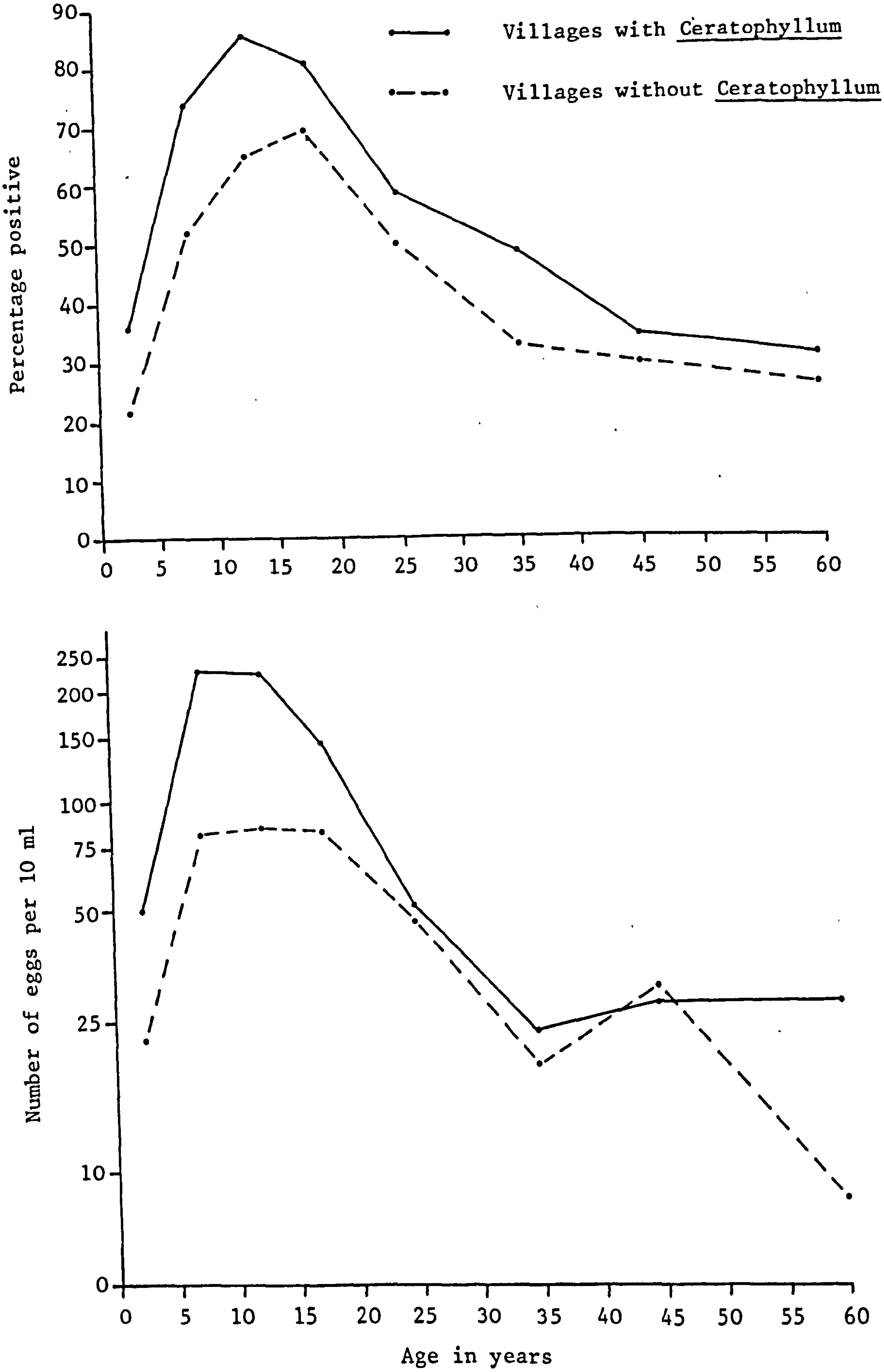

Fig. 33. Differences in age-specific prevalence rates of *S. haematobium* (top graph), and geometric means of egg output in positive 10 ml samples (bottom graph), between people living in villages where *Ceratophyllum* grew in WCPs, and in villages where it did not grow.

Protection by geographical location

Table 69 identifies 8 sampled villages that were clearly located at "exposed" sections of the lake, i.e., at wide open sections of the lake away from coves and inlets, where there was no natural protection to lessen wind and wave action. Since *B. rohlfsi* could not survive in "exposed" areas of the littoral zone, these "exposed" villages were therefore most "protected" against high transmission of *S. haematobium*.

Figure 34 shows the difference in prevalence rates and geometric means of positive egg counts between the 8 "protected" villages combined and the 22 remaining villages that were either located in stream inlets, coves, or at other sites where WCPs were at least partially sheltered against wave action by geography and/or significant weed growth.

The differences are highly significant, and indicate that the "protected" villages posed the least risk for *S. haematobium* infection.

It is important that public health engineers and planners consider this factor when planning the location of resettlement villages or towns in future man-made lakes. Siting villages away from narrow inlets and coves would not only be a natural defense against high transmission of *S. haematobium*, it would also make weed clearance on these shores a feasible means of achieving even greater control of transmission, since without macrophyte cover, wave action would preclude *Bulinus* species surviving in the littoral zone.

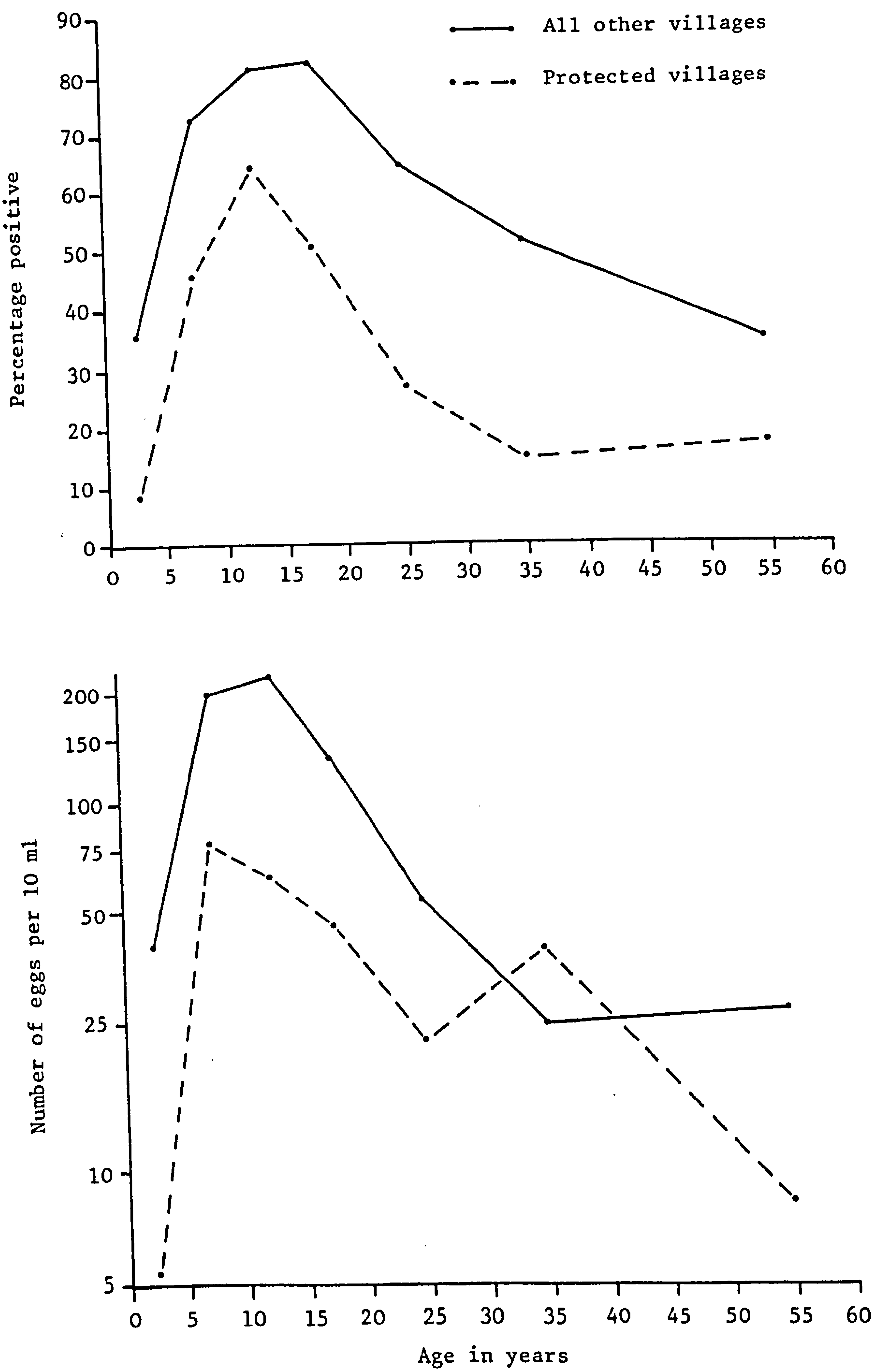

Fig. 34. Differences in age-specific prevalence rates of S. haematobium (top graph), and geometric means of egg output in positive 10 ml samples (bottom graph), between people living in villages that were naturally "protected" against high transmission because of shorelines that were exposed to wind and wave action, and in all other villages.

8.3.11 Correlation between snail sampling results on transmission potential and results from human surveys in villages

In the precontrol period of the WHO project in Ghana, a strong correlation emerged between overall snail sampling results on the percentage of times sampled WCPs per village yielded one or more infected *B. rohlfsi* and levels of human infection in the same villages - prevalence rates, geometric means of positive egg counts, and the product of the latter 2 indices (Klumpp and Chu, 1980). The results could be viewed with confidence because many WCPs were sampled per village, and because snail sampling continued up to 27 consecutive months. Although the above analysis failed to take into account varying levels of human water contact in different villages as well as different proportions of people in different age groups, it did show that snail sampling results reflected what was happening parasitologically in the human populations.

From the results of snail sampling and urine examination in the present study, it was also possible to match-up the same 2 sets of parameters. But because 7 villages included only school children, it was thought best to include only the 5 - 19 year-old group, in all 30 villages. This population was probably a more sensitive indicator of local transmission occurring than inclusion of all ages of people.

When calculating prevalence rates among the 5 - 19 year-olds, the statistical technique of indirect age standardization was used to correct for village by village variation in the proportion of children between 5 - 9, 10 - 14, and 15 - 19 years of age.[1] It was also necessary to correct the sums of the logs of the positive egg counts in the 3 age divisions per village. This was done by first figuring out the overall proportion of children in the 3 age divisions from all 30 villages, and using these standard ratios to calculate the weighted average of the log counts for the 5 - 19 year-old span per village. Geometric means were then calculated from the final weighted averages.

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[1] Standardizing the prevalence rates changed the uncorrected prevalence rates per village among the 5 - 19 year-olds by no more than ± 4% points.

Table 71 lists the village by village snail sampling results against the 3 respective, standardized indices of human infection.

The results show a significant correlation ($P < 0.05$) between the snail sampling results vs. (1) human prevalence rates, and vs. (2) geometric means of egg counts.

The fact that these correlations are not stronger is not surprising, considering the ecological variation noted around the lake, and that prevalence rates and geometric means of egg counts are not as sensitive to rapid changes in transmission as incidence rates.

The biggest descrepancy in the results occurred in the "Afram" villages - very little transmission detected by snail sampling but very high levels of human infected persisting. As stated earlier, the period of snail sampling in the Afram branch coincided with a period of excessive water pollution, caused mainly by too much weed growth in the littoral zone, which controlled peopulations of *B. rohlfsi*.

If all 6 of the "Afram" villages are eliminated from the analysis, the correlations in the remaining 24 villages become much stronger, and are significant at the 99% level or greater (Table 72).

Table 71. Results from 30 villages showing the percentage of times cercarial-infested WCPs were detected per village against the respective standardized human prevalence rates among 5 - 19 year-old residents, the geometric means of egg counts among the positive children, and the products of prevalence rate and geometric mean.

Village	% of times sampled WCPs were cercarial-infested (1)	Standardized prevalence rate (%) among 5-19 year-olds (2)	Corrected geometric mean of egg counts in positives (3)	Product: $\frac{(2)}{100} \times (3)$
Nahrpawnya	0	86.2	326	281
Dortopong	11.8	96.4	974	939
Kpetinu	12.5	93.5	229	214
Asuboni	5.0	75.1	97	73
Asumjeri	8.6	83.8	210	176
Dedekrom	0	92.5	492	455
Bridgeanu-A.	63.2	92.1	404	372
Konkra	73.7	95.5	1000	955
Sodzi Kope	50.0	95.2	287	273
America Kope	29.4	96.8	396	383
Ntonaboma	55.5	93.5	355	332
Sodzi Kope	40.0	75.7	82	62
Kpeve Tornu	0	70.4	33	23
Woadzi Tornu	0	30.6	5	2
Kpo Kope	15.0	100.0	53	53
Quarters	25.0	88.5	96	85
Vakpo Aneta	10.0	56.0	80	45
Agbenoxoe	40.0	61.1	122	75
Dafor Tornu	0	75.5	96	72
Amedzake Kope	17.5	100.0	471	471
Domiabra	31.6	90.8	141	128
Buipe	46.9	91.1	385	351
Abogysekrom	25.0	72.7	188	137
Kofi Bassari	34.4	55.7	114	64
Tornu No. 1	6.2	54.2	79	43
Prambo	56.2	68.9	55	38
Bladjei	23.1	79.8	58	46
Kitari	3.8	25.2	24	6
Kete Krachie T.	23.1	56.8	29	16
Borae	0	8.6	20	2
Correlation coefficient (r) of (1) vs: (2), (3), and (2) x (3)		.382	.394	.353
Level of significance, 28 d.f.		$P < 0.05$	$P < 0.05$	NS

Table 72. Coefficients of correlation between 24 individual village results of the percentages of cercarial-infested WCPs vs. the 3 observed parameters of human infection listed below, excluding the results from the 6 "Afram" villages.

	Standardized prev. rate among 5 - 19 year-olds (1)	Corrected geometric mean of egg counts among positives (2)	Product of (1) and (2)
Coefficient of correlation (r)	.566	.662	.648
Level of significance, 22 d.f.	$P < 0.01$	$P < 0.001$	$P < 0.001$

CHAPTER 9

RESULTS OF AN IN-DEPTH STUDY ON S. HAEMATOBIUM TRANSMISSION AT AGBENOXOE

9.1 INTRODUCTION

9.1.1 Studies conducted

Since 2 weeks were spent at the main field base, Agbenoxoe, each month, it was possible to conduct some detailed studies on the ecology of *S. haematobium* transmission in this large, non-fishing village. The purpose of this chapter is to present results of the research, with emphasis on the public health significance of the findings.

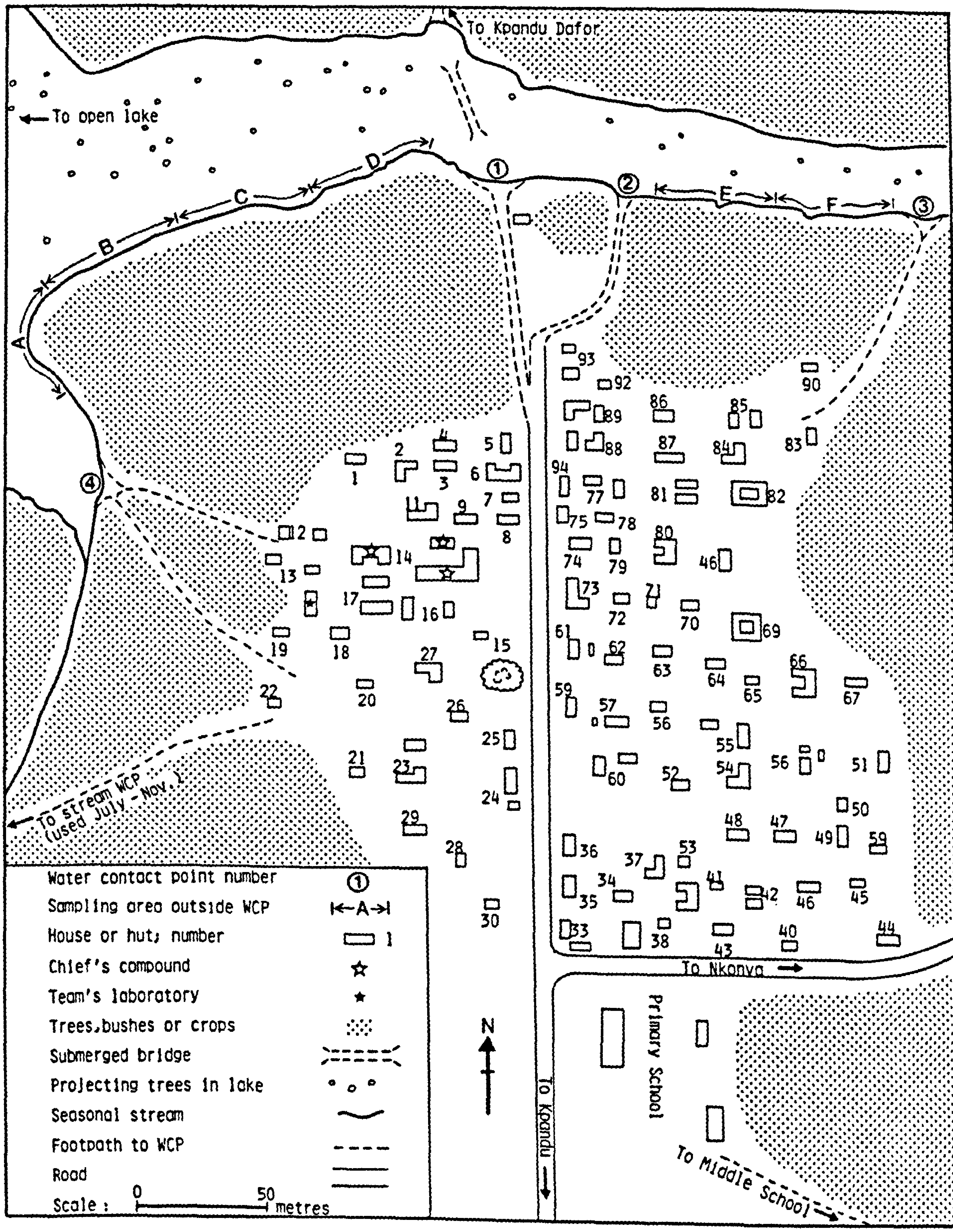
In addition to the routine snail sampling and the laboratory experiment on the growth, survivorship, and intrinsic rate of natural increase of *B. rohlfsi* already presented, the following work was conducted:

1. two surveys on *S. haematobium* prevalence rates and egg output among Agbenoxoe residents;
2. snail sampling in all lake WCPs, as well as along the entire village shoreline between the WCPs;
3. a study of the incidence of *S. haematobium* among a cohort of children; and,
4. human water contact observations at the 2 main WCPs.

Later, in June 1980, a chemotherapy campaign was carried out in the village. Over 80% of all residents who were known to be infected with *S. haematobium* were fully treated with metrifonate (Bilarcil) under the supervision of Dr. E.O. Laryea, Ghana Ministry of Health. A follow-up evaluation of the "specific population chemotherapy" was made by the author at Agbenoxoe in July 1981 - to be published in a later paper.

9.1.2 Description of the village

Agbenoxoe has existed as a village of between approximately 400 and 1200 people for over 100 years, although about a fifth of all households were flooded in 1964 - 1965 by the rising lake, and were relocated in the present cluster of houses (Map 14). The recorded population in 1980 was 1070.



Map 14

Agbenoxoe, showing location of houses, water contact points, and other features.

The village is famous throughout southern Ghana and parts of Togo for its Christian grotto, where numerous statues depict events of the Crucifixion (southwest corner of village; not shown on map). Religious groups make frequent one-day pilgrimages to the grotto, and on special occasions, thousands of people attend outdoor mass there.

Nearly all of the indigenous residents of Agbenoxoe are Catholics, baptised at infancy. These baptism are recorded, kept by families, and give recipients their true birth year.

A primary and middle school have existed in the village for decades. Almost all Agbenoxoe children attend school through primary level (6 years); about two-thirds also complete 4 years of middle school (to age of 18 or 19).

Except for about 50 - 70 semi-nomadic Efutu people who fish, and a few other "strangers", the village population is composed of indigenous "northern" Ewe people, who are primarily farmers. They have a different dialect from the "Anlo" and "Bator" Ewe fisherfolk from the coast and lower Volta River respectivley, who settled around the lake in largest numbers.

9.1.3 Reasons for choosing Agbenoxoe for detailed study

Agbenoxoe was selected for epidemiological study in early 1979. Then, early snail sampling results from 2 main WCPs indicated that a large population of *B. rohlfsi* existed in the high transmission season; and, an *ad hoc* sample of urine from 56 school children, aged 5 - 14, indicated a prevalence rate of 76%. From a VLRP survey in late 1972, the prevalence rate among 229 Agbenoxoe children of the same age was 25.1% (Jones, 1973). The increase in infection suggested that active transmission of *S. haematobium* was occurring in the village.

Being a compact village of over 1000 people and very close to the lake, it appeared to be a suitable choice for intensive study. No other lakeside village could be found with all the advantages of Agbenoxoe: (1) easy accessibility; (2) close proximity to a major town (Kpandu), (3) having both a large human and vector snail population, and (4) known age of most residents.

Plate 45. Main road separating east and west sides of Agbenoxoe.

Plate 46. Field laboratory at Agbenoxoe.

9.1.4 Living and working facilities

From July 1979 to June 1980, the Agbenoxoe chief and some of his relatives provided the author and each team member with a private room free of charge.

Living for a fortnight or so in the village each month enabled the team to expedite data collection, and more important, to win the trust and cooperation of the Agbenoxoe people.

Apart from the actual collection of snail and urine samples, all experiments and most examination of specimens took place in a field laboratory, specifically constructed for the research, from local materials, and with labour expenses, costing slightly under ¢1,000 (US $364).

9.2 RESULTS

9.2.1 Findings on prevalence rates and egg output of *S. haematobium* infection in the village

Introduction

Two epidemiological surveys were conducted at Agbenoxoe. The first took place in July and August 1979, the second in May 1980. The main purpose of the research was (1) to collect basic demographic information and (2) to compare levels of *S. haematobium* infection in relation to age, sex, and household location of residents.

Materials and methods

The form used for registering Agbenoxoe people, recording epidemiological information, and later, for recording details of chemotherapy is shown in Appendix D.

People were initially registered in their compounds during the first prevalence-intensity survey. Each family household had already been numbered with paint or chalk from an earlier census by the Ghana Government. The same numbers were used in the present research (Map 14).

The name, sex, age, and family position was recorded on a house-to-house basis. The 1979 census was updated in January 1980 and again in May 1980 when the second epidemiological survey was conducted. The age of each person was recorded in terms of July 1979, and as one year older in May 1980.

At times of urine collection, all 97 households and the 2 schools were visited by the team. In the second survey, urine samples were not taken for children under 2 years of age. The time of urine collection did not deviate between 1000 - 1400 h; most samples were taken from 1100 - 1300 h.

Urine samples were collected and processed in accordance with the standard method developed by the author (section 8.2.1). The Nuclepore filters were all of 25 mm diameter and 12 μm pore-size.

Participation rates

Except for 0 - 4 year-olds, the percentage of Agbenoxoe residents who provided urine samples was generally over 80% in both surveys (Table 73). Highest participation was in Survey 1 because more time was available to trace absentees.

Changes in Agbenoxoe population between Surveys 1 and 2

These are self explanatory in Table 74. Compared to fishing villages in the WHO study area and, presumably, other semi-nomadic fishing villages around the lake, Agbenoxoe had a stable population.

Table 73. Participation rates in epidemiological surveys.

Age group	No. of people who provided urine samples / No. of people registered in the village: Jul-Aug,'79	%	May 1980	%
0-4	87/135	64.4	46/116	39.7
5-9	136/153	88.9	147/178	82.6
10-14	134/134	100.0	137/153	89.5
15-19	124/143	86.7	145/169	85.9
20-29	88/113	77.9	100/159	62.9
30-39	61/76	80.3	74/94	78.5
40-49	68/80	85.0	70/87	80.5
50-59	46/51	90.2	44/51	88.2
60-69	31/37	83.8	36/40	90.2
70 +	22/23	95.7	22/23	95.7
Total	797/945	84.3	821/1070	76.7

Table 74. Changes in Agbenoxoe population between 1979 and 1980.

Year	Net population in village	No. of people who died or moved away	No. of newcomers: Semi-nomadic fisherfolk	Others
1979	945			
1979-'80		15[a]	71	69[b]
1980	1070			

[a] Known cases; true number probably greater. [b] Not including newborn children born outside of Agbenoxoe.

Table 73. Participation rates in epidemiological surveys.

Age group	No. of people who provided urine samples / No. of people registered in the village: Jul-Aug,'79	%	May 1980	%
0-4	87/135	64.4	46/116	39.7
5-9	136/153	88.9	147/178	82.6
10-14	134/134	100.0	137/153	89.5
15-19	124/143	86.7	145/169	85.9
20-29	88/113	77.9	100/159	62.9
30-39	61/76	80.3	74/94	78.5
40-49	68/80	85.0	70/87	80.5
50-59	46/51	90.2	44/51	88.2
60-69	31/37	83.8	36/40	90.2
70 +	22/23	95.7	22/23	95.7
Total	797/945	84.3	821/1070	76.7

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1979	945			
1979-'80		15[a]	71	69[b]
1980	1070			

[a] Known cases; true number probably greater. [b] Not including newborn children born outside of Agbenoxoe.

Population pyramid

An age pyramid of the Agbenoxoe population in Survey 1 is shown in Figure 35. The overall male-female ratio was 1 to 1.16 (437 males, 508 females). The pyramid differs slightly from the one constructed from the 23 sampled villages around the lake (page 254). At Agbenoxoe, there was a much higher proportion of children aged 15 - 19. This was probably because Agbenoxoe teen-agers stayed in the village to complete middle school. In semi-nomadic fishing villages, most teen-agers had to go elsewhere to attend school or find work.

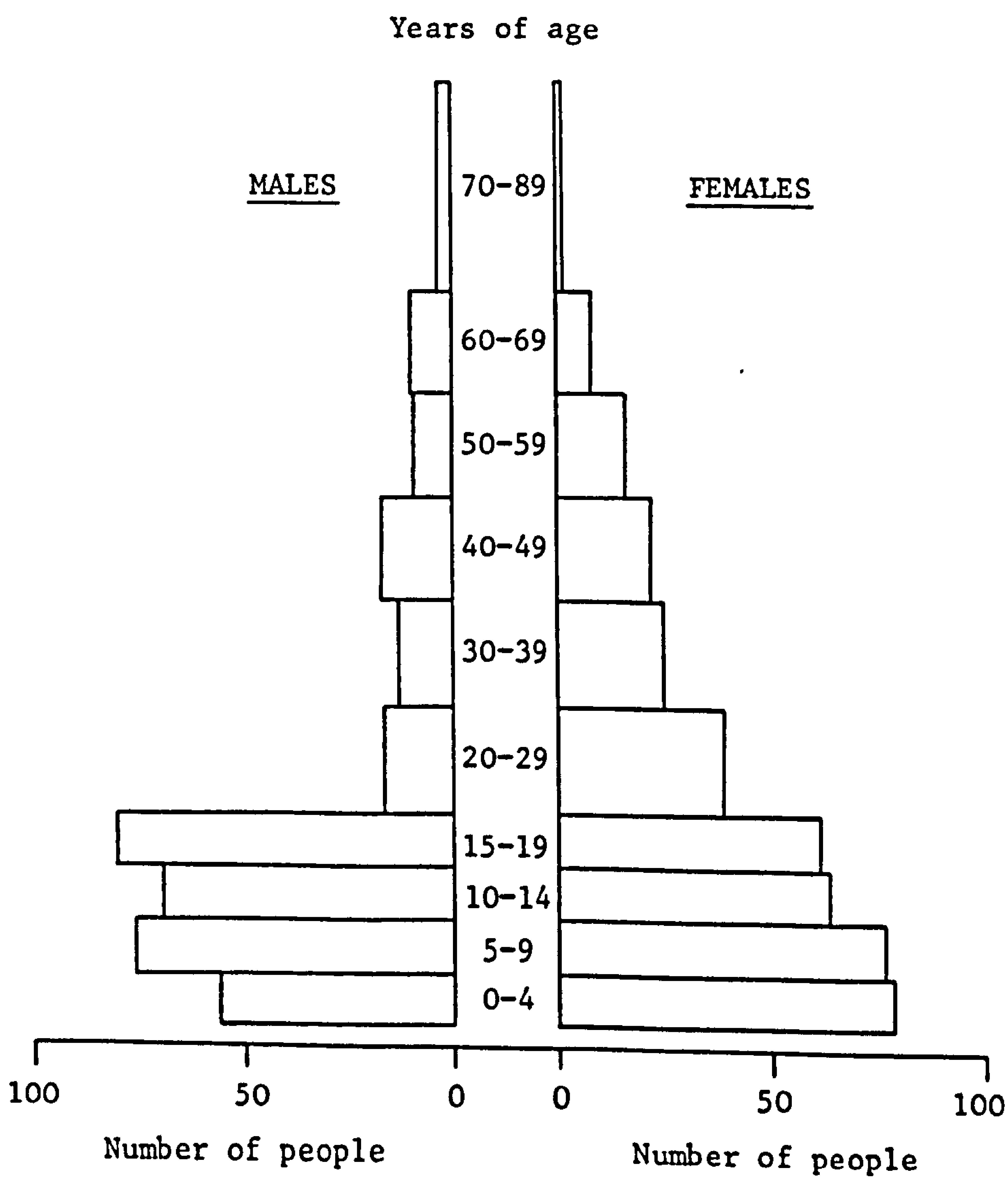

Fig. 35. Age pyramid at Agbenoxoe in 1979.

Comparison of prevalence rates by age and sex in Surveys 1 and 2

The age and sex breakdown of *S. haematobium* infection among all people examined is given in Table 75. In both surveys, prevalence rates for males were higher than for females in almost every age group, and the overall differences between the sexes were statistically significant (χ^2 testing, using Mantel-Haenszel test[1] to correct for differing proportions of people in the different age groups).

There was no significant difference in age and sex-specific prevalence rates between the 2 surveys. The slight overall increase in Survey 2 was due in part to the impact of 125 new residents in the village, who were first examined in May 1980. These people had an overall prevalence rate of 41.6%.

The first survey revealed the surprising fact that the *S. haematobium* prevalence rate in the village was greater than 50% in the 10 - 19 year-old age group only.

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[1] Personal communication with Richard Hayes, statistician, Tropical Epidemiology Unit, London School of Hygiene and Tropical Medicine.

Table 75. Comparison of prevalence rates by age and sex in Surveys 1 and 2.

	Number positive/Number examined, and prevalence rate (%)									
	Survey 1, 1979					Survey 2, 1980				
Age group	Males	%	Females	%	Both sexes,%	Males	%	Females	%	Both sexes,%
0-4	0/41	0	0/46	0	0	0/24	0	0/22	0	0
5-9	23/70	32.8	28/66	42.4	37.5	25/70	35.7	23/77	27.9	32.6
10-14	61/70	87.1	41/64	64.0	76.1	58/71	81.7	45/66	68.2	75.2
15-19	62/69	89.9	37/55	67.3	79.8	62/76	81.6	50/69	72.5	77.2
20-29	12/24	50.0	11/64	17.2	26.1	22/45	48.9	7/55	12.7	29.0
30-39	9/21	42.9	2/40	5.0	18.0	13/30	43.3	3/44	6.8	21.6
40-49	9/28	32.1	2/40	5.0	16.2	10/33	30.3	0/37	0	14.3
50-59	2/16	12.5	0/30	0	4.3	2/14	14.3	0/30	0	4.5
60 +	5/33	15.2	1/20	5.0	11.3	7/35	20.0	1/23	4.3	13.8
All ages	183/372	49.2	122/425	28.7	38.3	199/398	50.0	129/423	30.5	40.0
χ^2 value[a]	29.1 (P <.001)					32.8 (P <.001)				

[a] Mantel-Haenszel test

Comparison of geometric means of positive *S. haematobium* egg counts in Surveys 1 and 2

Table 76 compares the geometric means between infected males and females in each survey, while Table 77 compares differences between the 2 surveys.

In 1979 and in 1980, males had higher geometric means of egg counts than females in every age category and for all ages combined. Values were highest for 10 - 14 and 15 - 19 year-old males in 1979 and 1980 respectively.

Although prevalence rates remained stable between Surveys 1 and 2, geometric means of egg output did not. Apart from 0 - 4 year-olds, the latter values were greater for every age group in 1980, and applying the Student's t test, the differences were significant for 15 - 19 and 20 -29 year-olds, as well as for all ages combined (Table 77).

The finding at Agbenoxoe of stable prevalence rates of *S. haematobium*, but rapid changes in group egg output from year to year, agrees with the precontrol results from the WHO project in Ghana (Scott et al., 1982). It could also be the result of rapid changes in group egg output according to season, as described by Wilkins and Scott (1978) in the Gambia. Survey 2 at Agbenoxoe was conducted 2 months after the end of the high transmission season in 1980 while Survey 1 took place 4 - 5 months after the end of the high transmission season in 1979.

The increase in geometric means in 1980 cannot be attributed to the impact of new, positive residents who were first examined in 1980 (52 in all). Eliminating these people from the 1980 results did not change any of the age-specific results in a statistically meaningful way.

Table 76. Geometric mean of S. haematobium egg counts (per 10 ml) among all infected males and females in Surveys 1 and 2.

Age group	Survey 1, 1979 Males (n=183)	Survey 1, 1979 Females (n=122)	Survey 2, 1980 Males (n=199)	Survey 2, 1980 Females (n=129)
0-4	0	0	0	0
5-9	104	47	117	57
10-14	283	87	218	147
15-19	120	38	234	79
20-29	27	20	69	50
30 +	31	4	42	12
All ages	118	46	139	85

Table 77. Geometric mean of S. haematobium egg counts (per 10 ml) among all infected people in Surveys 1 and 2.

Age group	1979 (n=305)	1980 (n=328)	Level of signif. (t test) of diff. between means
0-4	0	0	-
5-9	67	83	NS
10-14	176	183	NS
15-19	79	144	$P < .005$
20-29	23	64	$P < .005$
30-39	20	36	NS
40 +	23	30	NS
All ages	81	115	$P < .05$

Applying two-stage catalytic model to observed age-prevalence results

Details of age-specific prevalence rates and egg counts for a narrow age breakdown of Agbenoxoe people examined in both surveys are given in Table 78. S. haematobium infection was a serious problem only among children aged 8 - 19. Among 10 - 19 year-olds, prevalence rates and egg counts were of the same magnitude as results obtained in the 23 sampled villages from different parts of the lake.

Observed age-prevalence results from Survey 2 have been plotted in Figure 36. (The 1980 results were more reflective of what occurred epidemiologically during the team's stay in the village.)

The unusual nature of the age-prevalence curve can be appreciated: (1) zero prevalence rates until age 5, (2) a logarithmic build-up of infection from ages 7 - 11, peak prevalence rates reached at age 16 - 17, (3) a very rapid decline from age 20 - 30, and (4) a maintenance of erratically low prevalence rates through the oldest age groups.

A 2-stage catalytic model was applicable to the 0 - 19 year-old age span (the approximate age of the Volta Lake). Since there was no infection detected under age 5, one 2-stage curve gave a good fit for the 5 - 19 age group.

Following the procedure for converting the instantaneous forces of infection (a) and loss of infection (b) into rates per year (page 269), the predicted annual incidence rate for 5 - 19 year-olds came to 19.7%, and the predicted annual rate of loss of infection ("outcidence" rate) was 2.3%.

Table 78. Details of prevalence rates and egg counts of S. haematobium in a narrow age grouping of all Agbenoxoe residents examined in 1979 and 1980.

Age group	Survey 1, 1979			Survey 2, 1980		
	No. + / No. exam.	Arith. mean	Mean of logs of eggs + 1	No. + / No. exam.	Arith. mean	Mean of logs of eggs + 1
0-1	0/20	0	0	-	-	-
2-3	0/38	0	0	0/26	0	0
4-5	3/55	2	0.061	4/51	2	0.092
6-7	18/64	66	0.452	17/60	192	0.583
8-9	30/46	362	1.372	27/56	239	0.964
10-11	38/56	529	1.545	42/59	389	1.598
12-13	38/47	340	1.712	40/52	316	1.764
14-15	50/57	817	2.069	47/58	720	1.982
16-17	45/54	312	1.464	57/69	351	1.727
18-19	30/44	212	1.274	29/44	331	1.296
20-24	18/55	26	0.505	24/65	108	0.699
25-29	5/33	2	0.126	5/35	7	0.216
30-39	11/61	9	0.246	16/74	19	0.347
40-49	11/68	24	0.267	10/70	38	0.277
50-59	2/46	1	0.049	2/44	4	0.073
60-69	5/31	3	0.188	4/36	6	0.151
70 +	1/22	1	0.022	4/22	4	0.188

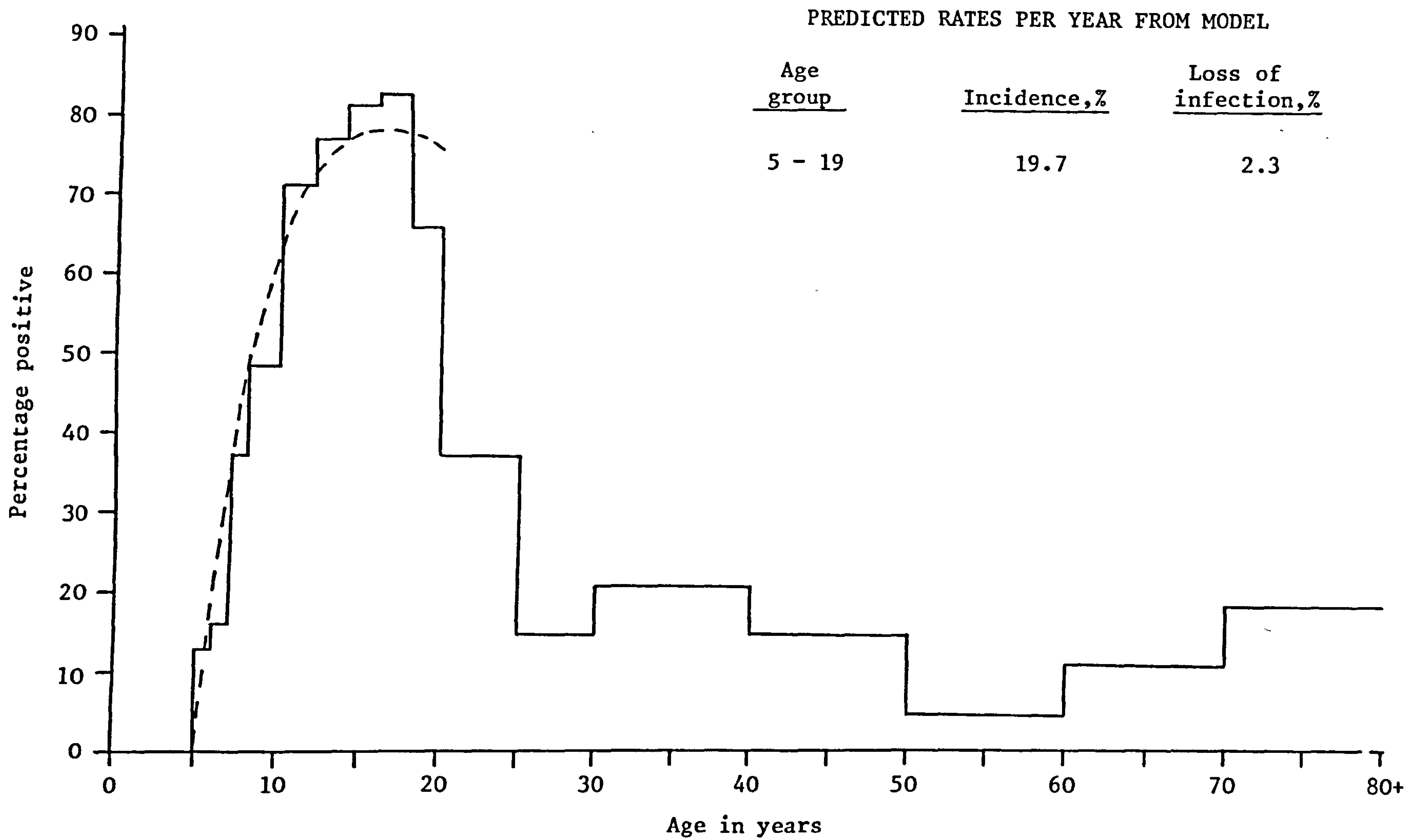

Fig. 36. Observed age-prevalence rates of S. haematobium among 0 - 80+ year-old Agbenoxoe residents in 1980, with a fitted 2-stage catalytic model for ages 5 - 19, enabling prediction of annual incidence rate and annual rate of loss of infection for the latter age group.

Evidence of a non-random distribution of *S. haematobium* infection at Agbenoxoe

For the analysis which follows, age-specific prevalence rates and geometric means of egg output are compared for Agbenoxoe residents in different groupings of households (1980 data). The first comparison is between levels of infection in all people living on the "west side" of the village (west of N.-S. road bisecting village; Map 14) against those of all people living on the "east side" of the village. The second comparison of infection is between all residents who (from interviews at all households) claimed to have water contact in WCP 4 throughout the year, vs. all those who claimed to go to WCP 3 each season[2].

WCPs 4 and 3 were the most heavily-used WCPs in the village. Over 90% of people living on the west side of the road and 16 families on the east side used WCP 4 most frequently. Thirty-three families on the east side went mainly to WCP 3, and 16 families used WCPs 1 and 2, or other combinations of WCPs. The semi-nomadic fisherfolk always went to WCP 1 for fish-related activities, but sometimes used WCP 2 for bathing.

Later results from snail sampling will show that WCP 4 had the highest transmission potential in 1980, followed in descending order by WCPs 3, 2, and 1.

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[2] This analysis involved families that claimed to use only WCP 4 or only WCP 3, and not families that also used points besides WCP 4 or WCP 3. While the people in the analysis must have had some water contact in other WCPs, it was probably sporadic. Data for other families were not as precise, especially people who used WCPs 1 and 2, which were close together and used by strangers.

Table 79 shows that the overall S. haematobium prevalence rate of residents living on the west side of Agbenoxoe was significantly higher than among residents from the east side. Except for 0 - 4 and 20 - 39 year-olds, rates for west-side residents were highest in all age groups.

The intensity of S. haematobium infection was also consistently highest among west-side residents. This can be seen in Table 80 which compares geometric means of egg output for all age of importance.

What caused this non-random distribution of infection at Agbenoxoe? The answer can be deduced from inspection of Tables 81 and 82. After the lake reached the village, people on the west side must have had most frequent water contact in WCP 4. It was the closest WCP to most west-side houses. From November 1979 to June 1980, WCP 4 contained 3.4 times more infected B. rohlfsi than WCP 3, 4.9 times the number from WCP 2, and 9.1 times the number found in WCP 1. It was therefore the most dangerous transmission point.

Table 81 shows that overall prevalence rates among the consistent male and female users of WCP 4 were significantly higher than among the males and females who consistently used WCP 3. The rates were higher in every age group except 20 - 29 year-old females.

The geometric means of positive egg counts between the regular users of WCP 4 or WCP 3 agreed with the prevalence findings. Egg counts were higher in all important age groups of males and females associated with WCP 4 (Table 82).

Table 79. Comparison of 1980 prevalence rates of *S. haematobium* between all people living on the west and east side of Agbenxoe.

Age group	West of road: No. positive / No. examined	%	East of road: No. positive / No. examined	%	χ^2 test[a] between overall prev. rates
0-4	0/19	0	0/27	0	
5-9	26/56	46.4	22/91	24.2	
10-14	41/45	91.1	62/92	67.4	
15-19	33/38	86.8	79/107	73.8	
20-29	8/31	25.8	21/69	30.4	
30-39	5/25	20.0	11/49	22.4	
40-49	5/22	22.7	5/48	10.4	
50-59	1/14	7.1	1/30	3.3	
60 +	3/20	15.0	5/38	13.2	
All ages	122/270	45.2	206/551	37.4	12.36 ($P < .001$)

[a] Mantel-Haenszel test

Table 80. Comparison of geometric means of *S. haematobium* egg counts (per 10 ml) between all infected people living on the west and east side of Agbenoxoe.

Age group	West of road	East of road
5-9	95	71
10-14	233	156
15-19	187	129
20-29	76	60
30 +	46	32
All ages	140	102

Table 81. Comparison of 1980 prevalence rates of *S. haematobium* between people who used either WCP 4 or WCP 3 as their main point of water contact.

Age group	WCP 4 users: No. positive / No. examined	WCP 4 users: %	WCP 3 users: No. positive / No. examined	WCP 3 users: %	χ^2 test[a] between overall prev. rate
MALES					
0-4	0/12	0	0/2	0	
5-9	11/26	42.3	5/18	27.7	
10-14	25/26	96.3	9/14	64.3	
15-19	23/26	88.5	16/19	84.2	
20-29	9/13	69.2	4/12	33.3	
30-49	10/22	45.4	3/15	20.0	
50 +	5/24	20.8	0/8	0	
All ages	83/149	55.7	37/88	42.0	10.85 ($P < .001$)
FEMALES					
0-4	0/9	0	0/3	0	
5-9	11/30	36.7	2/21	9.5	
10-14	21/26	80.8	3/16	18.8	
15-19	20/25	80.0	11/14	78.6	
20-29	2/20	10.0	2/11	18.2	
30 +	3/56	5.4	0/28	0	
All ages	57/166	34.3	18/93	19.4	11.63 ($P < .001$)

[a] Mantel-Haenszel test

Table 82. Comparison of geometric means of S. haematobium egg counts (per 10 ml) among infected males and females who had most frequent water contact in either WCP 4 or WCP 3.

Age group	Males		Females	
	WCP 4	WCP 3	WCP 4	WCP 3
5-9	229	20	69	5
10-14	229	158	157	11
15-19	371	177	66	57
All ages	155	119	89	27

9.2.2 Study of the seasonality, relative intensity, and focality of transmission at Agbenoxoe by snail sampling

Introduction

Monthly and seasonal changes in numbers of infected *B. rohlfsi* and total *B. rohlfsi* collected were monitored in WCPs 1 and 2 for 20 continuous months, from November 1978 to June 1980 (plus sampling results for September 1978).

Additional sampling was carried out in WCPs 3 and 4 during 8 consecutive months (November 1979 to June 1980) to determine the importance of each of the 4 village WCPs for transmission potential.

A final snail sampling experiment, from January to June 1980, took place along the entire, unused part of the south shore at Agbenoxoe. Its purpose was to ascertain transmission potential outside of WCPs. No published study of this kind had been conducted before in the Volta Lake or in any other large man-made lake.

When routine sampling began at Agbenxoe in November 1978, only WCPs 1 and 2 had significant water contact. Then, the extremely low level of the lake polluted WCP 3 too much for regular use, and the micro-inlet containing WCP 4 was about to dry up. After the 6 m rise of the lake level in late 1979, WCPs 3 and 4 were again in regular use. Except for the unusual low use in 1979, WCP 4 had always been the most heavily-used WCP by the village residents, followed in descending order of use by WCPs 3, 1, and 2.

However, WCP 1 was an important crossing point for strangers, who travelled by canoe to and from Kpandu Dafor and Dafor Tornu. In drought periods, it was also a main WCP for fetching water, for hundreds of non-residents living in scattered households up to 5 km from Agbenoxoe.

Materials and methods

All snail sampling at Agbenoxoe followed the standard, man-time method that was used by the team at all other lakeside villages of study. Thus, each of the 4 team members searched non-stop for 15 minutes per WCP (or area) to equal 1 man-hour of sampling.

Nearly all snail sampling in the village was accomplished between the 4th and 8th day of the month.

The distances along the shoreline in which sampling was conducted in the 4 WCPs ranged from 20 - 50 m, depending on the intensity of human water contact and vegetation. The total sampling area per search in the WCPs ranged from 80 - 150 m^2.

The sampling effort inside and outside the WCPs was essentially the same. For the special study away from the WCPs, searches were conducted in 6 fixed sampling areas. These were designated A - F (Map 14). Each area was about 60 m in length, following the curvature of the shoreline. Each team member searched along a separate, 15 m section per area, always within 2 m of the water's edge.

Results

1. Seasonality of transmission

The 21 months of snail sampling results from WCPs 1 and 2 are presented in Table 83. In assessing the seasonal nature of transmission, it is best to consider the overall mean number of infected *B. rohlfsi* collected per month (i.e., with patent *S. haematobium* cercariae). Thus, the highest transmission potential occurred in November, followed closely by December and January. Transmission potentials were surprisingly low from February to May, and apart from June, were very low (as expected) from July to October.

The results in Table 83 are different from the monthly and seasonal transmission potentials from all 39 villages sampled around the lake (page 132), which showed highest transmission potentials from December to April, and a low potential for November. Apart for November, numbers of *total* snails collected in WCPs 1 and 2 agreed more closely with findings from the other villages.

Table 83. Total number of infected *B. rohlfsi* per total number of all *B. rohlfsi* collected in WCPs 1 and 2, with calcualted relative monthly index of transmission potential (ITP), based on mean number of infected snails per WCP.

WCP	Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	1978-79	1/29	NS	6/161	8/149	2/12	0/18	0/2	0/11	0/17	1/5	0/1	0/7
1	1979-80	0/5	0/3	0/6	0/22	5/58	1/80	0/50	0/11	0/6	1/8	-	-
2	1978-79	0/1	NS	3/13	3/17	2/18	0/9	3/9	0/1	0/6	0/15	0/9	0/16
2	1979-80	0/11	1/1	5/5	0/6	2/44	0/53	0/42	2/37	0/14	4/21	-	-
Total		1/46	1/4	13/185	11/194	11/132	1/160	3/103	2/60	0/43	5/59	0/10	0/23
Mean No. + snails per WCP (1)		0.25	0.50	3.25	2.75	2.75	0.25	0.75	0.50	0	1.50	0	0
Relative ITP, %*		2.0	4.0	26.0	22.0	22.0	2.0	6.0	4.0	0	12.0	0	0

* Calculated as follows. Each value of (1) divided by $\Sigma(1)$ times 100.

Because numbers of infected snails were low at WCPs 1 and 2, a more accurate assessment of the main months for transmission at Agbenoxoe can be made by examining total sampling results from all 4 village WCPs combined, over the final 8 months (Table 84).

Table 84. Total number of infected B. rohlfsi over total number of all B. rohlfsi collected in WCPs 1 - 4 combined (Nov. 1979 - June 1980), with calculated transmission potentials.

	1979	1980						1979
	Dec	Jan	Feb	Mar	Apr	May	Jun	Nov
Infected snails / Total snails	9/100	31/286	14/546	26/298	9/106	1/36	8/100	5/16
Mean No. infected snails per WCP	2.25	7.75	3.50	6.50	2.25	0.25	2.00	1.25
Relative Index of trans. potential,%								
1. monthly	8.7	30.1	13.6	25.2	8.7	1.0	7.8	4.9
2. seasonal		77.6				22.4		

The calculated transmission potentials for this more limited period of sampling indicate that 77.6% of transmission would be expected between December and March, while only 22.4% would be expected in the other 4 months. These results conform more closely to the overall results from the 39 villages.

2. Relative intensity of transmission potential in the different WCPs

Details of snail catches in the 4 WCPs between November 1979 and June 1980 are presented in Table 85. The results give a good indication of the importance of each point in terms of danger for transmission.

During the 8 months, the most consistently dangerous transmission point was WCP 4. It accounted for 62.1% of all infected snails collected. In descending order of danger came WCPs 3, 2, and 1.

Table 85. Number of infected *B. rohlfsi* over total number of all *B. rohlfsi* collected in WCPs 1,2,3, and 4, November 1978 - June 1980.

WCP	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total	% of + snails from 4 WCPs
1	$\frac{0}{6}$	$\frac{0}{22}$	$\frac{5}{58}$	$\frac{1}{80}$	$\frac{0}{50}$	$\frac{0}{11}$	$\frac{0}{6}$	$\frac{1}{18}$	$\frac{7}{251}$	6.8
2	$\frac{5}{5}$	$\frac{0}{6}$	$\frac{2}{44}$	$\frac{0}{53}$	$\frac{0}{42}$	$\frac{2}{37}$	$\frac{0}{14}$	$\frac{4}{21}$	$\frac{13}{222}$	12.6
3	$\frac{0}{1}$	$\frac{4}{24}$	$\frac{10}{86}$	$\frac{2}{215}$	$\frac{3}{83}$	$\frac{0}{10}$	0	$\frac{0}{8}$	$\frac{19}{427}$	18.4
4	$\frac{0}{3}$	$\frac{5}{48}$	$\frac{14}{98}$	$\frac{11}{198}$	$\frac{23}{123}$	$\frac{7}{48}$	$\frac{1}{16}$	$\frac{3}{17}$	$\frac{64}{551}$	62.1

3. Snail sampling to determine transmission potential away from WCPs

The sampling results from the 6 areas are given in Table 86. Twenty-six of the 56 total infected snails (46.4%) were collected in Area A, nearest to WCP 4 (Map 14). Infected specimens were found there during each of the 6 months. In that period, more infected snails were found in Area A than in any WCP except WCP 4. Far fewer snails were collected in the other areas, but between January and June about as many infected *B. rohlfsi* were found in Areas B, E, and F as in WCPs 1 and 2 respectively.

The high number of infected snails found in Area A was due to it being a favourite fishing point by 8 - 16 year-old boys. One 15 year-old was seen urinating in Area A in April 1980. There seemed to be only one other well-defined, possible transmission point in the 6 areas. This was a family-worked vegetable garden in Area B. But throughout the study (and other times) few people besides 8 - 16 year-old boys were ever seen in the water outside the 5 village water contact points (including the stream WCP).

A better way to compare transmission potentials in the areas away from the WCPs with those inside WCPs is to convert the raw totals of infected and total snails per sampling area to mean values per metre of shoreline sampled. These are given in Table 87.

The coverted results indicate that apart from Area A, "density" (mean number) of infected snails per m shoreline sampled (x 100) was greater inside the WCPs than outside them. By contrast, "density" of all *B. rohlfsi* collected was only slightly greater inside the WCPs (158 vs. 121).

Table 86. Number of infected B. rohlfsi over total number of all B. rohlfsi collected in areas along shore but away from WCPs, 1980.

Area	Jan	Feb	Mar	Apr	May	Jun	Total	Infection rate.%
A	$\frac{4}{174}$	$\frac{6}{257}$	$\frac{5}{142}$	$\frac{1}{27}$	$\frac{5}{32}$	$\frac{5}{26}$	$\frac{26}{658}$	4.0
B	$\frac{0}{154}$	$\frac{3}{222}$	$\frac{2}{136}$	$\frac{0}{1}$	$\frac{0}{12}$	$\frac{3}{8}$	$\frac{8}{533}$	1.5
C	$\frac{0}{51}$	$\frac{0}{86}$	$\frac{1}{66}$	$\frac{0}{9}$	$\frac{0}{84}$	$\frac{0}{2}$	$\frac{1}{298}$	0.3
D	$\frac{0}{51}$	$\frac{1}{62}$	$\frac{1}{115}$	$\frac{0}{24}$	$\frac{2}{26}$	$\frac{1}{11}$	$\frac{5}{289}$	1.7
E	$\frac{1}{57}$	$\frac{6}{186}$	$\frac{2}{139}$	$\frac{0}{10}$	$\frac{0}{2}$	$\frac{0}{10}$	$\frac{9}{404}$	2.2
F	$\frac{2}{114}$	$\frac{3}{171}$	$\frac{0}{121}$	$\frac{0}{1}$	$\frac{2}{23}$	$\frac{0}{5}$	$\frac{7}{434}$	1.6
Total	$\frac{7}{601}$	$\frac{19}{984}$	$\frac{11}{719}$	$\frac{1}{72}$	$\frac{9}{179}$	$\frac{9}{61}$	$\frac{56}{2616}$	2.1

Table 87. Comparison of total mean numbers of _B. rohlfsi_ collected per 100 metres of shoreline sampled, in areas away from WCPs and inside WCPs.

	Area away from WCPs							WCP number				
	A	B	C	D	E	F	Total	1	2	3	4	Total
Total length of shoreline sampled in metres	360	360	360	360	360	360	2160	265	165	200	215	895
Mean no. of infected snails per metre shoreline x 100	7.2	2.2	0.3	1.4	2.5	1.9	2.6	2.6	4.8	7.5	27.4	10.5
Mean no. of total snails per metre shoreline x 100	183	162	83	80	12	121	121	84	128	201	233	158

Discussion

From the snail sampling results, one can conclude that the high transmission season at Agbenoxoe can range from November to March. Transmission is usually sporadic between April and July and is consistently low from August to October.

The analysis of the relative transmission potential in the individual WCPs at Agbenoxoe supports the epidemiological findings that (1) the distribution of infection is not uniform, and (2) people who have water contact in WCP 4 most frequently face the greatest risk of infection.

The study of transmission potential outside of water contact points gives further evidence that transmission is focal - largely confined to these recognized points, even though some infected snails are present along the entire shore. There is no evidence to suggest that human water contact in the village is significant outside of the WCPs.

9.2.3 Results of a longitudinal study to determine incidence rates of *S. haematobium* among Agbenoxoe children

Farooq and Hairston (1966) described the importance of incidence rates in epidemiological studies of schistosomiasis. Shiff (1973) emphasized the value of assessing incidence rates by season for monitoring rapid changes in schistosome transmission.

The first longitudinal study on precontrol incidence rates of *S. haematobium* at the Volta Lake was conducted in the WHO study area between 1974 and 1975 (Scott et al., 1982). Over 100 initially negative persons of all ages (mainly children) were examined monthly over 3 successive days for evidence of infection. The study was handicapped by high absenteeism, significant inter-village movement by the fisherfolk, a shortage of negative subjects in high transmission areas, and incorrect calculation of seasonal incidence rates (listed as point prevalence rates). However, inspection of the raw data shows that incidence of *S. haematobium* at the Volta Lake was distinctly seasonal. Of 28 people who converted to positive over the one-year period of assessment (and assuming a two-months' incubation period for worm patency), 23 people got infected between November and April while only 5 got infected from May to October. These results agreed with seasonal results of transmission potential in the same period as detected by snail sampling (Klumpp and Chu, 1977).

At Agbenoxoe, a longitudinal study of incidence rates among a cohort of children aged 3 - 14 years of age was conducted between August 1979 and June 1980. The problems associated with the earlier incidence study at the Volta Lake were largely eliminated. Many negative children were available, within easy reach for examination, and the problem of children having contact with other village WCPs was virtually absent.

The purpose of the present study was to test whether there was seasonal variation in the rate at which children in the cohort got infected, and to see if incidence rates varied greatly by age and sex.

Materials and methods

1. Selection of cohort

About 80 children between the ages of 5 and 14 who were negative in the first prevalence survey were tested for evidence of *S. haematobium* over 3 successive days between 18 and 20 August 1979. Seventy-one were negative and selected to form the cohort.

Thirty-five additional children, aged 3 and 4, were screened in a similar manner between 9 and 11 September 1979. Of these, 33 were added to the cohort.

Thus, the initial cohort number was 104. Among the 10 - 14 year-old group, it was possible to find only 22 negative subjects in the village who were readily available for later examination. All subjects were "northern" Ewes. Because of baptismal records and the high percentage of children attending school, age determination was accurate.

The cohort was selected mainly from households where inhabitants used either WCP 4 or WCP 3 almost exclusively. There was an approximate balance of subjects scattered between the west and east sides of the village. The male-female ratio was roughly equal through age 9. Among 10 - 14 year-olds, there were twice as many females as males.

2. Times of follow-up examinations

The first follow-up screening period was from 8 - 10 December. This was to monitor any changes during the lowest period of transmission (as detected by snail sampling). The second and final screening took place between 18 - 20 June 1980. Because of the heavy work load of the team, it was not possible to do more frequent monitoring.

During each period of screening, urines were collected between 0800 - 1200 h. (For practical reasons, urine collection could not be limited to 1000 - 1400 h).

3. Attendance

Detailed attendance figures are presented with results. About 90% and 88% of the initial cohort was examined over at least 2 of the 3 consecutive days in the December and June follow-ups respectively. In each period, over 80% of attending children were examined on all 3 days. Children positive in December were checked again in June.

On the evening before the start of each screening period, parents or relatives of the children were reminded to escort the younger ones to the team's laboratory at the appropriate time and to ensure that the older children reported as well. This produced good attendance on each day of testing during initial screening and in December, but many children had to be "chased-down" by team members and volunteers in June.

Urine collection, processing, and examination all took place at the field laboratory under strict supervision.

4. Method of urine examination

The Nuclepore method was used in all examinations. The children were asked to produce as much urine as possible in provided containers. The samples were left to sediment for about 1 hour. Then, 10 ml of urine from the bottom of each container was withdrawn by syringe and injected through the filters that were held within Swin-Lok chambers. The subsequent examination was done in the standard manner, described in section 8.2.1.

Contamination was controlled by using separate urine cups, syringes and Swin-Lok chambers for each subject. After each screeining, used equipment was thoroughly washed and dried in the sun.

5. Calculation of incidence rate

The formula for incidence rate follows that given by Farooq and Hairston (1966) except that the power value is expressed in days rather than months.

$$I = 1 - X^{(365/y)} \times 100$$

where I = annual incidence rate, X = proportion remaining negative, 365 = days in year, y = number of days between the 3rd (or last) day of each screening period of relevance, and 100 = constant to give a percentage value.

Results

1. Seasonal differences

Table 88 lists the number of children of each age group who converted to positive at the end of each follow-up period over the examined number who were negative at the start of the period, and gives seasonal incidence rates for the main age groups.

Among the 3 and 4 year-olds, only 1 girl converted between September and December.

For 5 - 9 year-olds, the incidence rate for August to December was 6.9%; during December to June, it increased to 39.8%.

For the 10 - 14 year-old group, the incidence rate was 37.5% for August to December, and 28.2% for December to June.

For all 5 - 14 year-olds, the incidence rate was 17.9% between August and December, and 36.1% from December to June. Even in this broader age span, absolute numbers of converts to positive were low, and because of this, a χ^2 test of significance between the 2 seasonal incidence rates would not have had much relevance.

Table 88. Details of children in the cohort converting to positive, and overall incidence rates according to season.

Age (yrs)	Starting number in cohort 11/9/1979	Number becoming positive between each of the 2 periods of examination over total number who were negative at the start of each period. (Incidence rates in %.)	
		Sep.-Dec.(92 days)	Dec.-Jun.(189 days)
3	17	0/13	0/10
4	16	1/14	0/13
3-4	33	13.9%	0%
	20/8/1979	Aug.-Dec.(114 days)	
5	14	1/12	1/10
6	11	0/11	3/10
7	14	0/14	1/12
8-9	10	0/9	4/7
5-9	49	6.9%	39.8%
10-11	11	1/11	2/10
12-14	11	2/11	1/9
10-14	22	37.5%	28.2%
5-15	71	17.9%	36.1%

2. Overall differences by age and sex

In Table 89, incidence rates are analysed according to sex in the 3 main age groups, for the overall period of August or September to June.

Apart from 3 - 4 year-olds, incidence rates were 2 - 3 times higher in males than females. Within each sex, they were highest among 10 - 14 year-olds, and increased most rapidly among boys between the ages of 5 and 9.

Among all 5 - 14 year-olds of both sexes, the incidence rate of 30.2% was 11.5% higher than the predicted incidence rate per year for 5 - 19 year-olds from the catalytic model for Agbenoxoe (page 301). This is not surprising considering:

(1) sensitivity in detecting positives was greater in the cohort study;

(2) true incidence rates probably declined after age 15;

(3) transmission was especially heavy in 1980;

(4) the cohort contained a disproportionately large number of children who had had most frequent water contact in WCPs 3 and 4.

Table 89. Number of male and female children in cohort becoming positive in either December or June over total number who were negative at the start of study, and calculated annual incidence rates (%).

Age (yrs)	Total days	Males	%	Females	%	Both sexes,%
3-4	281	0/12	0	1/12	10.7	5.4
5-9	303	7/18	44.7	3/22	16.7	29.3
10-14	303	3/7	49.0	3/15	23.6	31.9
5-14			46.0		19.2	30.2

3. Detection of positive urine samples during the 3 successive days of examination

Of the 17 children who first converted to positive, either in December or June, 59% were detected on the first day of examination, 24% on the second day, and 17% on the third day.

Six of those first converting were found to contain a maximum of 1 - 5 eggs per 10 ml in any of the 3 consecutive days; 7 had 6 - 15 eggs; 2 produced 15 - 90 eggs; and 2 had between 104 - 172 eggs.

In the same group, 6 children demonstrated eggs on all 3 days; 5 on 2 days; and 3 on 1 day. The 3 remaining positives were present on 2 days and showed eggs on 1 day.

4. Reversions from positive to negative

Two of the 5 children that were positive in December were still positive in June; 2 reverted to being negative; and 1 was absent on all 3 days. Both of the children who reverted to negative had less than 5 eggs/10 ml in December, showing eggs on only 1 day each.

Discussion

The incidence study at Agbenoxoe confirms results from snail sampling in the village that transmission is highest in the 6 months' period of November - April and lowest between May - October (assuming 2 months for worm maturation after cercarial penetration).

Since the present study also agrees with the earlier finding by Scott et al.(1982) about seasonal variation in incidence rates at the Volta Lake, it provides more evidence that despite quantitative differences in incidence rates between location and time, the basic, qualitative, seasonal pattern of transmission of *S. haematobium* at the Volta Lake has remained stable.

9.2.4 Preliminary analysis of water contact observations at WCP 4

Introduction

Despite the need to understand the complex ecology of human schistosomiasis, few studies have been published on the water contact behaviour of the main "vector" of the infection - man.

The earliest quantitative report of merit on human water contact observations in relation to S. haematobium infection in Africa was by Farooq and Mullah (1966) in the Egypt-49 Project. This was followed by other published studies in Zimbabwe (Husting, 1968), at the Volta Lake in Ghana (Dalton and Pole, 1978), and in Nigeria (Tayo, Pugh, and Bradley, 1980).

The study of Dalton and Pole was at the village of Fatem in the WHO study area. Although carefully designed in theory, the published report (ibid) did not always show exact correspondence between data and conclusions. Aspects of the methodology of data collection in the study was also questionable, especially the use of only 2 assistants working continuously from 0600 - 1800 h during each day of observation, each trying to record the exact time every resident spent in the water.

Dalton and Pole's method of data collection would not be suitable in crowded WCPs where scores of people enter and/or leave the water about the same time. This drawback was inherent in the design of other studies mentioned above.

At Agbenoxoe, human water contact observations were conducted at WCPs 4 and 1 over a period of 8 consecutive months, on 7 different days of the week each month. In this study, a new approach to the collection of data was initiated, and will be described. This method, or an improvement of it, could be of value for water contact observations in large villages in general.

The main purpose of the observations at Agbenoxoe was (1) to explain age and sex-related differences in S. haematobium infection in the village, and (2) to identify those water contact activities which create the highest and lowest risk of getting infected.

Plate 47. WCP 4 at a time of little water contact.

Plate 48. Women gathering at WCP 1 to buy fish from Efutu fisherfolk.

From the great mass of data collected - over 27,000 entries into WCPs 4 and 1 - results presented in this section could be based on a sample only of the data, and that only from WCP 4.

For the analysis, information from 2 of the 7 observation days per month were selected at random. By chance, this turned out to be a well-balanced sample - 3 Mondays, 2 Tuesdays, 2 Wednesdays, 2 Thursdays, 1 Friday, 2 Saturdays, and 2 Sundays.

However, the results obtained from this sample of data will not necessarily represent the full range of water contact activities in all WCPs in the village, especially WCP 1 where canoe-related activities took place. WCP 4 was mainly used for collecting water, and few canoes were present at the site. However, WCP 4 was by far the most heavily-used WCP, and from the epidemiological and malacological evidence already presented, it was the most dangerous transmission point.

Materials and methods

1. Original study design

The study design was to record the frequency, duration and type of water contact activity of each person who entered WCPs 4 and 1 at specified periods. The days of observation at the 2 main WCPs were the same - 7 different days of the week each month, from November 1979 through June 1980. Time of observation was continuous from 0600 - 1800 h.

2. Observers

Four young adults from Agbenoxoe were employed to collect all data after November 1979. Two males worked at WCP 1 and 2 females at WCP 4. All had completed middle school at Agbenoxoe and one of each sex had completed secondary school. Each knew the names of most Agbenoxoe residents before the study began, and soon became familiar with the names and age groupings of almost all Agbenoxoe residents who used the 2 WCPs. The observers were trained by the author at WCPs 4 and 1 during October and November 1979. Their presence at the WCPs did not seem to affect normal water contact patterns of behaviour, except perhaps, urination. Because the author resided in the village, close supervision of the observers was maintained.

3. Working hours and conditions

During each day of data collection, each observer worked for 6 continuous hours, either from 0600 - 1200 h or 1200 - 1800 h. Work shifts were normally changed after every observation day to provide variety and give both observers the chance to work equal periods on the easier morning shift.

The observers were stationed on shore, not more than 20 metres from the respective WCPs. They stood, or sat on provided stools. With no natural shade at the WCPs, portable sun shelters were constructed from bamboo poles and palm branches. Each observer worked with a clipboard, pen, file box with sufficient recording forms, and timing equipment.

4. Method of recording data

The recording form used is shown on the next page. When people were about to enter a WCP, the name, sex, and age group of each person was written in the appropriate space. This was done for future computer analysis, to link-up individuals with their total frequency and duration of water contact by activity. Age was grouped in years as 0 - 4, 5 - 9, 10 - 14, 15 - 19, 20 - 29, 30 - 39, 40 - 49, and 50 +. Strangers to Agbenoxoe who had water contact were identified only by sex and a guess at their age group. Strangers who stepped in the water for only a few seconds were not included in the records.

When a person entered the water, the abbreviation of the water contact activity was written, and time spent in the water recorded. Seven main activities were recognized: (1) collecting water, (2) washing (clothes or utensils); (3) wading or playing; (4) bathing; (5) swimming; (6) entering/exiting canoes; and (7) resting legs in the water while sitting on a berthed canoe.

The time spent in the water was marked with a "tick" in the appropriate time slot: in minutes as 0-1, 1-2, 2-3, 3-4, 4-5, or 5-10. If a person made repeated visits into the water in the same hour, it was not necessary to write the name again. Additional marks were made in the correct time slots.

WATER CONTACT STUDIES - AGBENOXOE

Date ____________ Hour ____________

Weather ____________________________

Observer ____________________________

CODE		ACTIVITY
FW	=	Fetching water
WAD	=	Wading
WAS	=	Washing
SW	=	Swimming
CE	=	Canoe enter/exit
BA	=	Bathing
DL	=	Dangling legs from canoe

				Minutes in water						
Name	Sex	Age group	Activ. code	0-1	1-2	2-3	3-4	4-5	5-10	U

If a person engaged in 2 or 3 different activities per hour, the second or third activity code and corresponding time were differentiated by placing circles or squares around them.

Whenever a person was seen urinating in the WCP, the "U" column for the person was marked.

Initial observations revealed that duration of water contact per entry was generally short. Because swimming was banned by the Agbenoxoe chief and mean duration of other activities was rarely over 10 minutes per entry, the longest time slot on the recording form was 5 - 10 minutes. Subsequent tabulation of individual marks from this time slot were always recorded as 7.5 minutes. The mid points of the other time slots were used as well.

When many people entered the water at about the same time, some guesswork was involved in recording time. But since collecting water was by far the most dominant activity and usually took less than 1 minute to complete per individual entry, it was not too difficult to distinguish those who stayed in the water continuously longer than 1 minute.

Results

1. Degree of water contact each month

From November to June, there was a clear seasonal trend in the frequency and duration of water contact (Figure 37). The end of the rainy season was usually in Novmeber, and from August to November 1979, the traditional stream WCP was used by many families for collecting water. (There were no medically important snails in the stream.) The stream dried up late November, accounting for the big increase in water contact at WCP 4 in December. The degree of contact continued to increase there throughout the dry season. The rainy season started abruptly in May, and this caused a big drop-off of water contact that month and in June. During rainy periods, most families in the village were able to collect sufficient rain water for household activities from rooftop drainage into converted oil drums. The majority of houses had corrugated aluminium roofs.

The total time spent in the water each month roughly followed the frequency curve except that duration of water contact was highest in January - the most dangerous month for *S. haematobium* transmission.

2. Variation in water contact during the day

Each month, most frequent water contact at all Agbenoxoe WCPs occurred between 06 - 07 h and 17 - 18 h. Figure 38 shows the variation during the day at WCP 4 for consecutive 2-hour periods. The morning and evening peaks of water contact were almost entirely caused by people collecting water in buckets for household activities like bathing, cooking, and washing.

The mean time spent in the water per entry was inversely proportional to the frequency of entries. Longest duration of water contact per entry took place between 12 - 14 h. This was also the peak period for cercarial shedding.

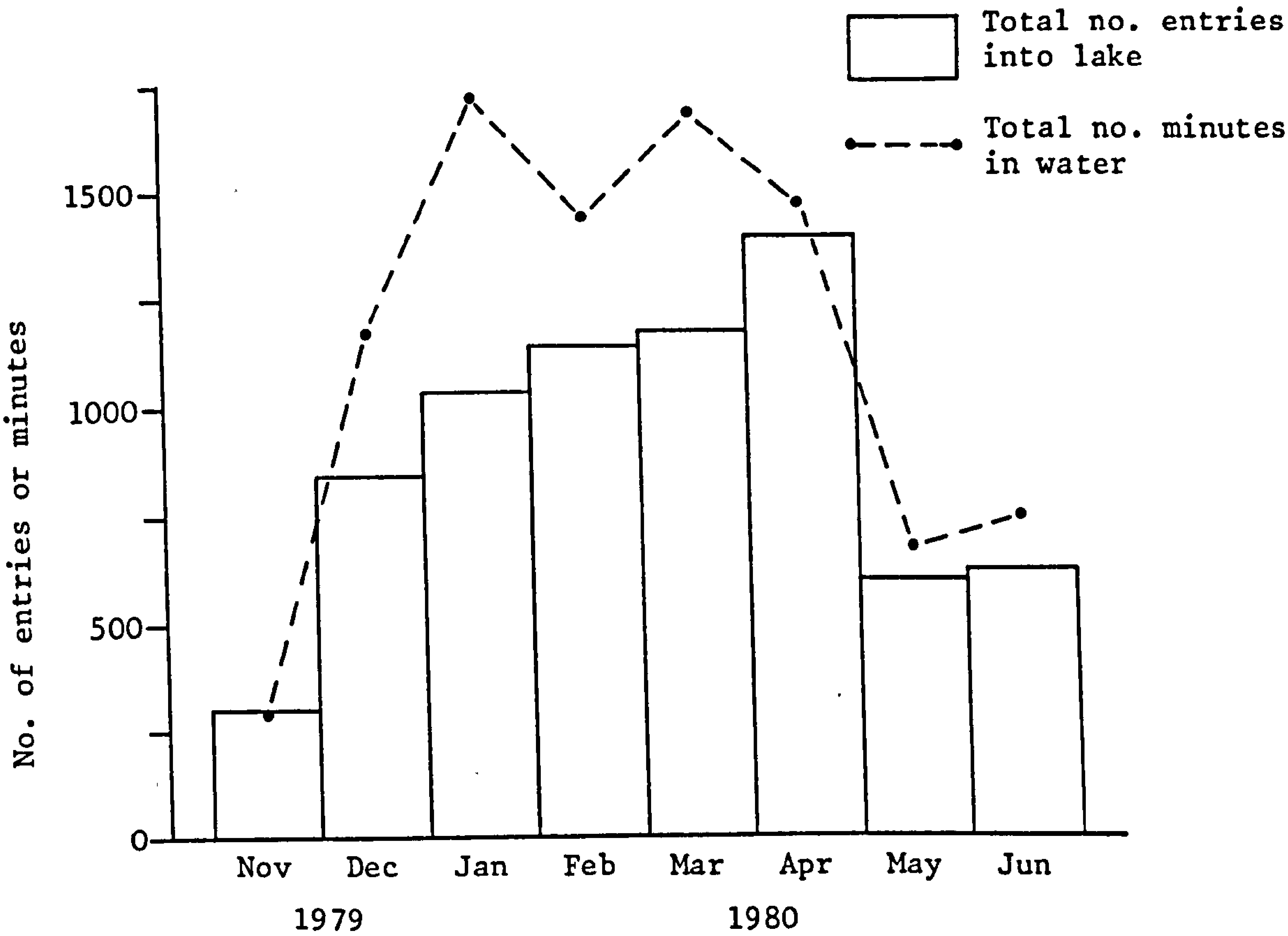


Fig. 37. Degree of water contact by month.

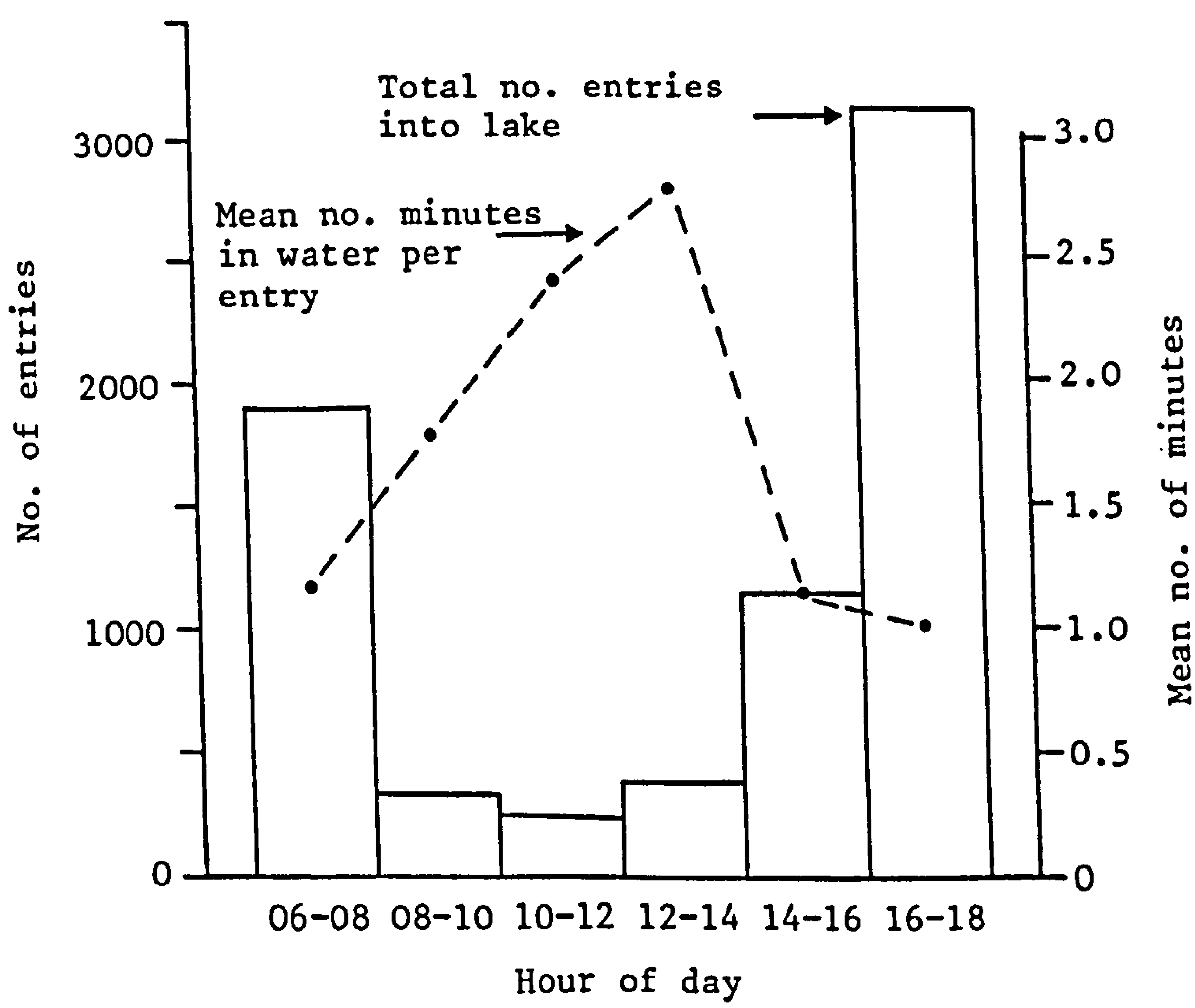


Fig. 38. Degree of water contact by hour of day.

3. Degree of water contact by age, sex, and activity

The total results from the sample of water contact data involving differences by age, sex, and activity are presented in Tables 90 and 91, and interpreted in the following pages.

The column for the "number of people at risk" follows tabulation of the age and sex breakdown of all families at Agbenoxoe who, upon being interviewed, claimed to use WCP 4 most frequently, if not exclusively.

The latter information enables standardization of the raw totals in the 2 tables for differing numbers of males and females in the different age groups who used WCP 4 at some time or other.

In the analysis that follows, all results comparing different ages (except mean time in water per entry) were standardized by dividing the age-specific totals of frequency and duration of water contact for each sex by the relevant number of people who were at risk.

Differences in water contact by age and sex

These standardized results can be seen in Figure 39. Apart from 0 - 4 year-olds, who almost never entered the water, females had much greater frequency of water contact than males for all age groups.

But the differences in time spent in water per person at risk was not so great between the sexes, and 10 - 14 year-old boys actually spent the most time in the lake by number.

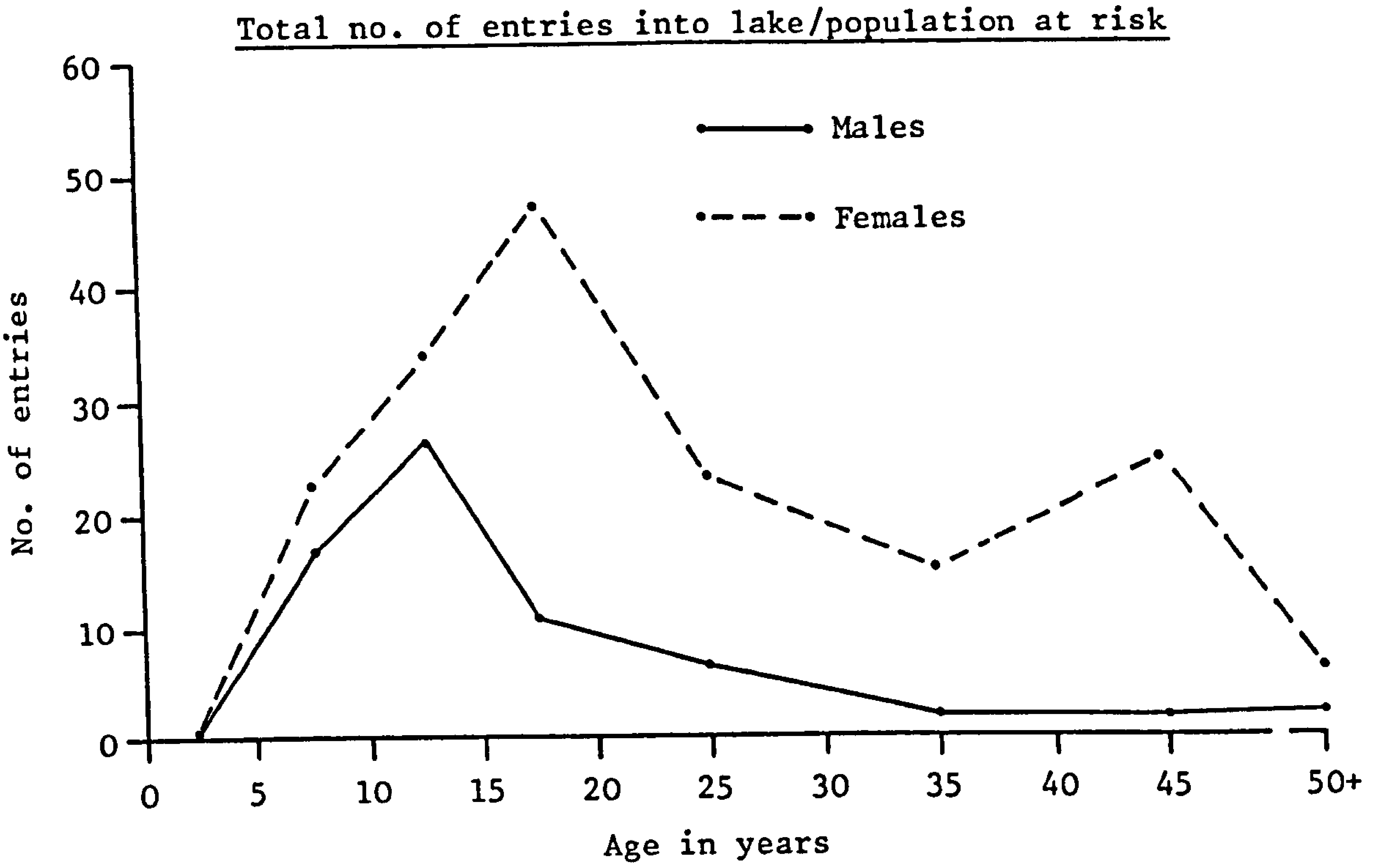
The age-specific curves of water contact in Figure 39 reflect most age-prevalence curves for *S. haematobium* infection - a rapid build-up from 5 - 14 years, a rapid drop-off after 15 - 19 years, a slow tail-off among adults, with the chance of a small secondary peak among older adults.

Table 90. Frequency of water contact according to activity.

Age group	No. people at risk	Number of entries into lake: Collecting water	Wading or playing	Washing	Other	Total
Females						
0-4	39	3	0	0	0	3
5-9	39	872	6	14	2	894
10-14	33	1089	9	33	1	1132
15-19	25	1149	0	25	0	1174
20-29	41	948	2	11	0	961
30-39	32	444	1	14	0	459
40-49	13	314	0	3	0	317
50+	30	180	1	1	0	182
Total	252	4999	19	101	3	5122
Males						
0-4	38	2	0	0	1	3
5-9	36	545	35	10	20	610
10-14	33	692	134	17	16	859
15-19	37	307	57	15	13	392
20-29	18	99	8	5	1	113
30-39	9	7	6	3	1	17
40-49	27	9	14	4	4	31
50+	22	41	5	7	1	54
Total	210	1702	259	61	57	2079

Table 91. Duration of water contact according to activity.

Age group	No. people at risk	Minutes spent in water				
		Collecting water	Wading or playing	Washing	Other	Total
Females						
0-4	39	1	0	0	0	1
5-9	39	814	40	112	15	981
10-14	33	983	60	232	4	1279
15-19	25	922	0	184	0	1106
20-29	41	749	15	78	0	842
30-39	32	390	4	84	0	478
40-49	13	258	0	22	0	280
50+	30	156	1	4	0	161
Total	252	4274	120	716	19	5129
Males						
0-4	38	1	0	0	4	5
5-9	36	449	256	110	90	905
10-14	33	602	928	114	83	1727
15-19	37	230	404	112	74	820
20-29	18	77	55	38	8	178
30-39	9	4	45	22	8	79
40-49	17	6	95	28	25	154
50+	22	38	38	52	4	132
Total	210	1407	1821	476	296	4000



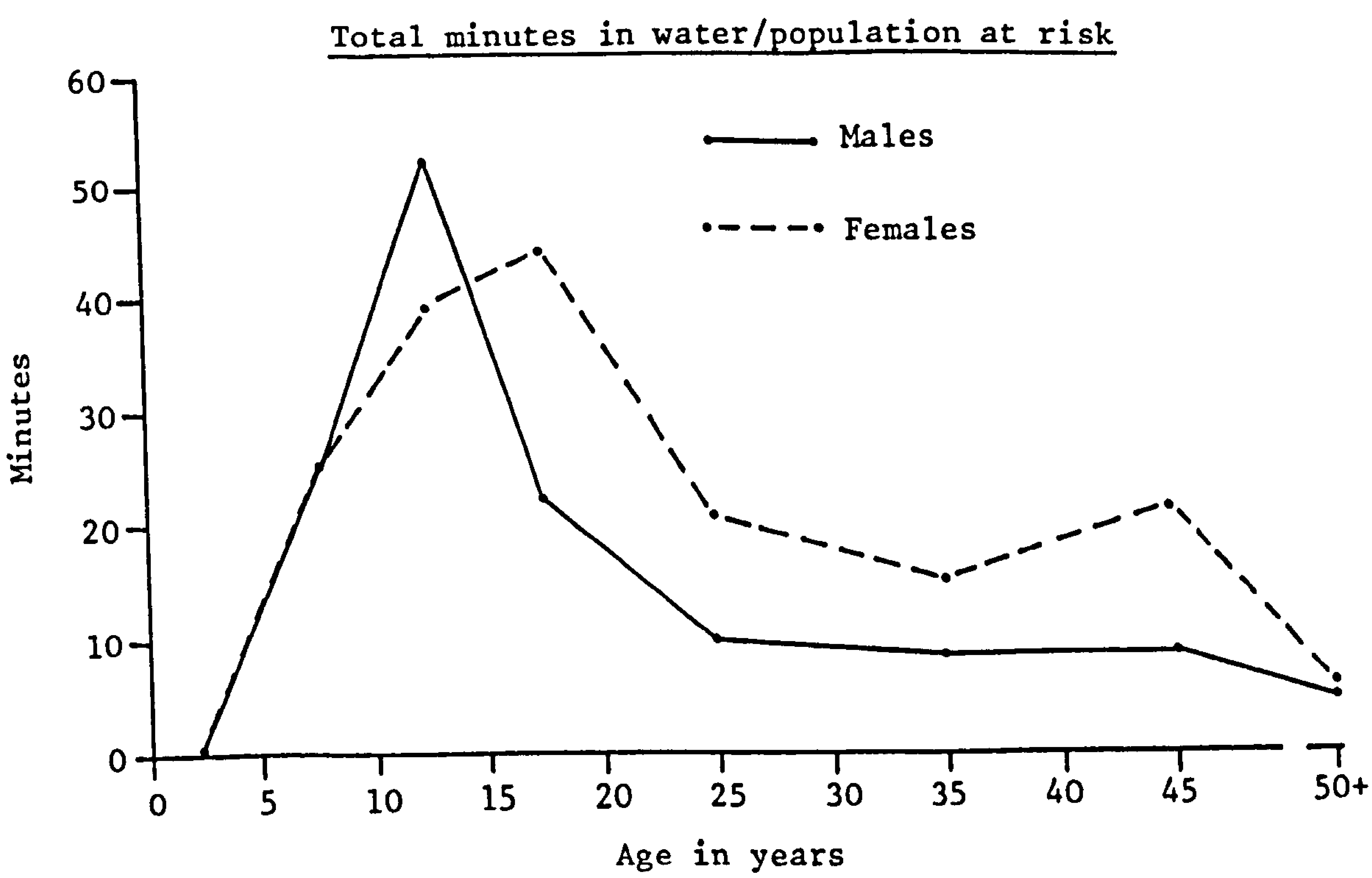


Fig. 39. Frequency and duration of water contact, by age and sex.

Differences in duration of water contact by type of activity

The dominant activity in WCP 4 was collecting water. This accounted for 97.6% of all female entries into the lake and 83.3% of all their time spent in the water. For males, collecting water accounted for 81.7% of the frequency, and 35.2% of the duration of water contact.

Males and females collected water by walking into the WCP with a bucket, to about mid-thigh depth, either resting the bucket on their head, squatting down, and filling it while it was still on their head with a large cup-shaped "calabash", or, more commonly, dipping the bucket in the water to fill it before lifting it back on their head, often with assistance from others.

Collecting water for household use was mainly the duty of females and 5 - 14 year-old boys. Adult men rarely engaged in this activity.

Differences in the total duration of age-specific water contact by type of activity divided by the females and males at risk are illustrated in Figure 40.

Wading or playing was almost entirely a male activity. It amounted to 45.5% of the total duration of water contact, and was the dominant time-consuming activity among 10 - 14 and 15 - 19 year-old boys. Among females, it amounted to only a small fraction of the duration of water contact by 5 - 9 and 10 - 14 year-olds.

Washing of clothes in WCP 4 was mainly performed by 10 - 14 year-old girls, although, in absolute terms, was significant for 15 - 19 year-old girls as well. It also accounted for much of the total duration of water contact among males of all age groups from age 15. Washing was most frequently performed between 08 - 12 h, and was most common on weekends.

Because few canoes were kept at WCP 4, little canoe-related activity was observed. Swimming and bathing were rarely seen.

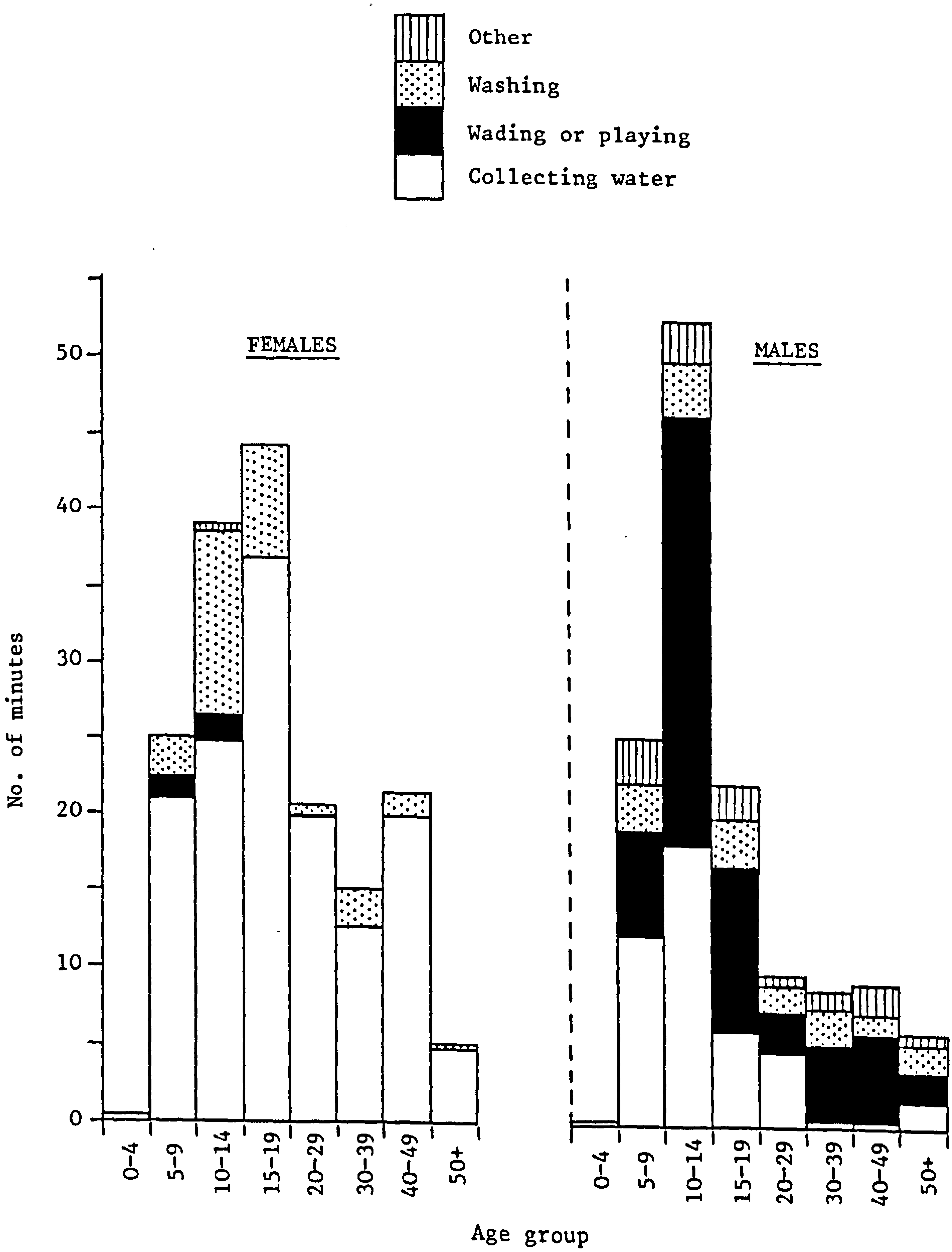


Fig. 40. Duration of water contact per person at risk, according to activity.

Which type of activity was "least dangerous" for getting infected? From results of mean time spent in water per entry, either collecting water or in all other activities (Figure 41), it is obvious that the activity of least risk for infection was collecting water. Even though engaged in most frequently, each separate entry into the water lasted on average under 1 minute, which combined with the disturbance of water created by large numbers of people collecting water at the same time when this activity predominated (morning and evening peaks of water contact), must have greatly reduced the chance of successful penetration by S. haematobium cercariae.

Which type of activity was "most dangerous" for getting infected? By the recording form design, there was virtually no difference shown in mean duration of water contact per entry among any of the activities observed apart from collecting water. However, from reviewing the frequency of long-lasting water contact activities (Table 90), the implication is that washing of clothes was the most dangerous activity for females and wading or playing was the most dangerous activity for males.

Figure 42 shows that mean time spent in the water per entry was greater for males than for females in every age group of importance. And since males participated most frequently (in terms of their number) in time-consuming water activities as wading, playing, washing, and some canoe-related work, it is logical to assume that such greater participation was responsible for causing the significantly higher rates of S. haematobium infection for males vs. females among WCP 4 users (Figure 43).[4] Among females alone, high prevalence rates and egg counts were only found in 10 - 14 and 15 - 19 year-olds, and only these girls engaged frequently in activities of long duration.

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[4] These results are slightly different from those for WCP 4 users presented in Tables 81 and 82. In the present analysis, 1979 ages were used because observers recorded ages to that year; secondly, the broadest grouping of WCP 4 users was included - not just people who used WCP 4 "exclusively".

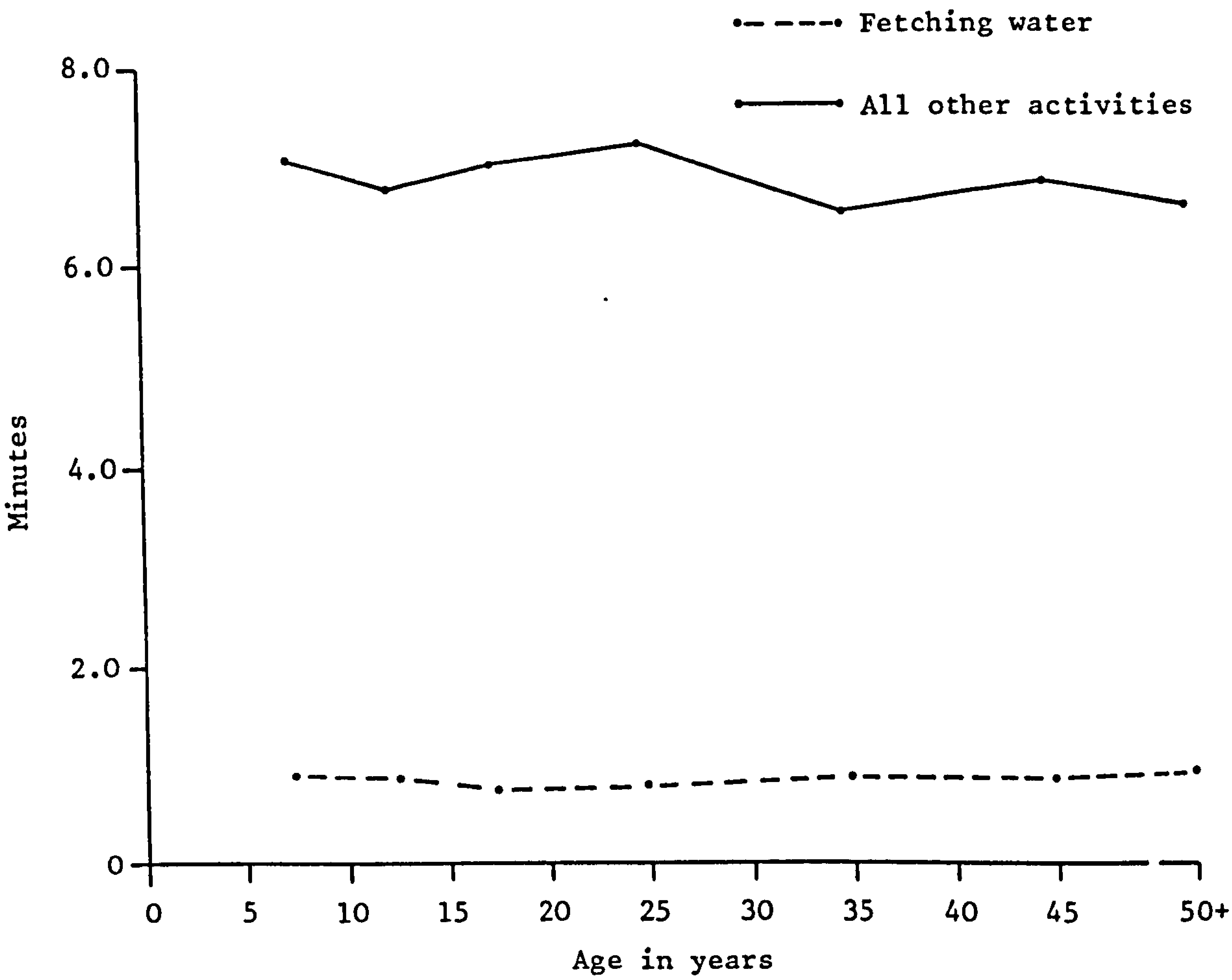

Fig. 41. Mean time spent in water per entry according to 2 main types of water contact.

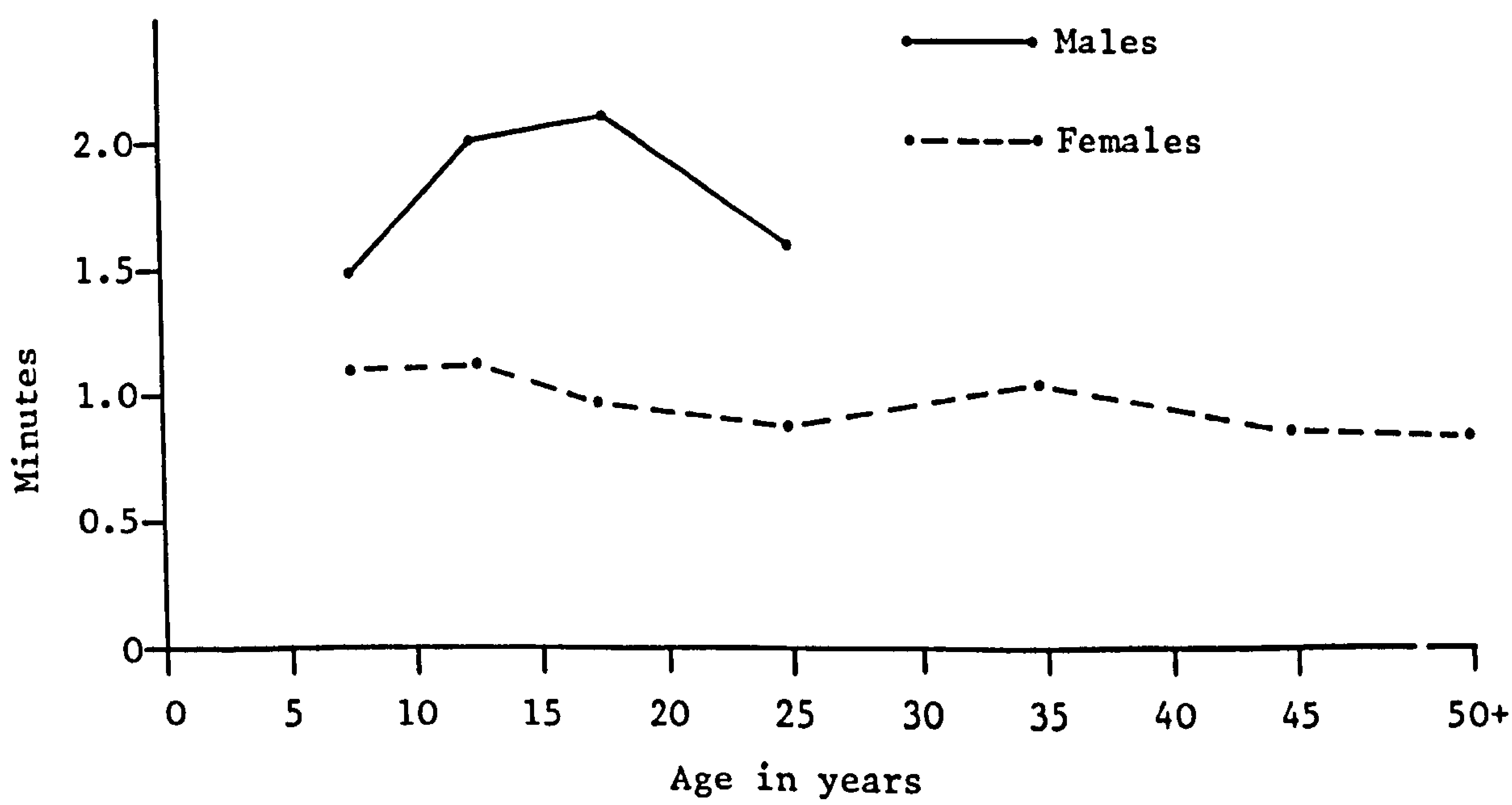

Fig. 42. Mean time spent in water per entry, by sex.

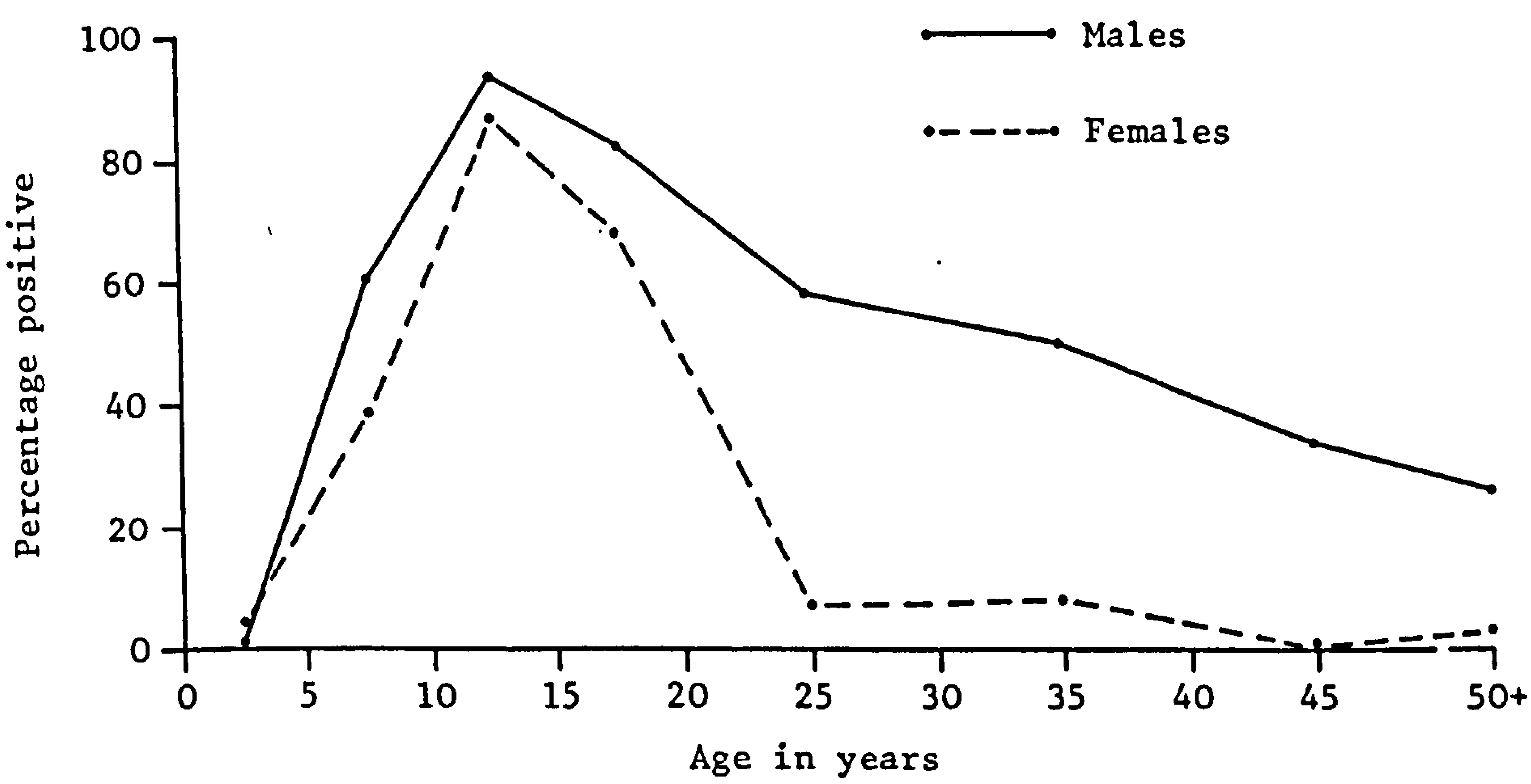

Fig. 43. Prevalence rates of S. haematobium among Agbenoxoe residents using WCP 4 most frequently.

4. Comparison of age-specific curves of duration of water contact and geomtric means of egg counts + 1

The geometric mean of S. haematobium egg counts (plus 1 egg per 10 ml urine sample) of the population at risk who used WCP 4 as their main WCP was calculated for each sex and age group (plotted on logarithmic scale). This was then compared with the age-specific curves of the standardized duration of water contact per population at risk (Figure 44).

For males, increase in egg counts with age up to 14 years closely followed the arithmetic increase in time (per group) spent in the water. After age 15, duration of water contact, in general, decreased slightly faster than the corresponding drop-off in egg counts. Thus, there is no evidence to imply that the decrease in "intensity" of infection among adult males was due to any obvious effect of immunity. Rather, changes in duration of water contact among males seemed to be the main factor affecting change in "intensity" of infection.

The superimposition of the 2 curves for females could imply the following: (1) either there was some type of immunity conferring protection to women beyond age 15, (2) the dominant activity of collecting water by adult women posed little risk of acquiring new infections, and/or (3) a combination of these two factors led to a rapid die-off of the group's worm load.

Whatever the case may be, it must be re-iterated that the analysis represents only a sample of data from Agbenoxoe, plus the fact that the Volta Lake did not represent a long-term, stable epidemiological situation.

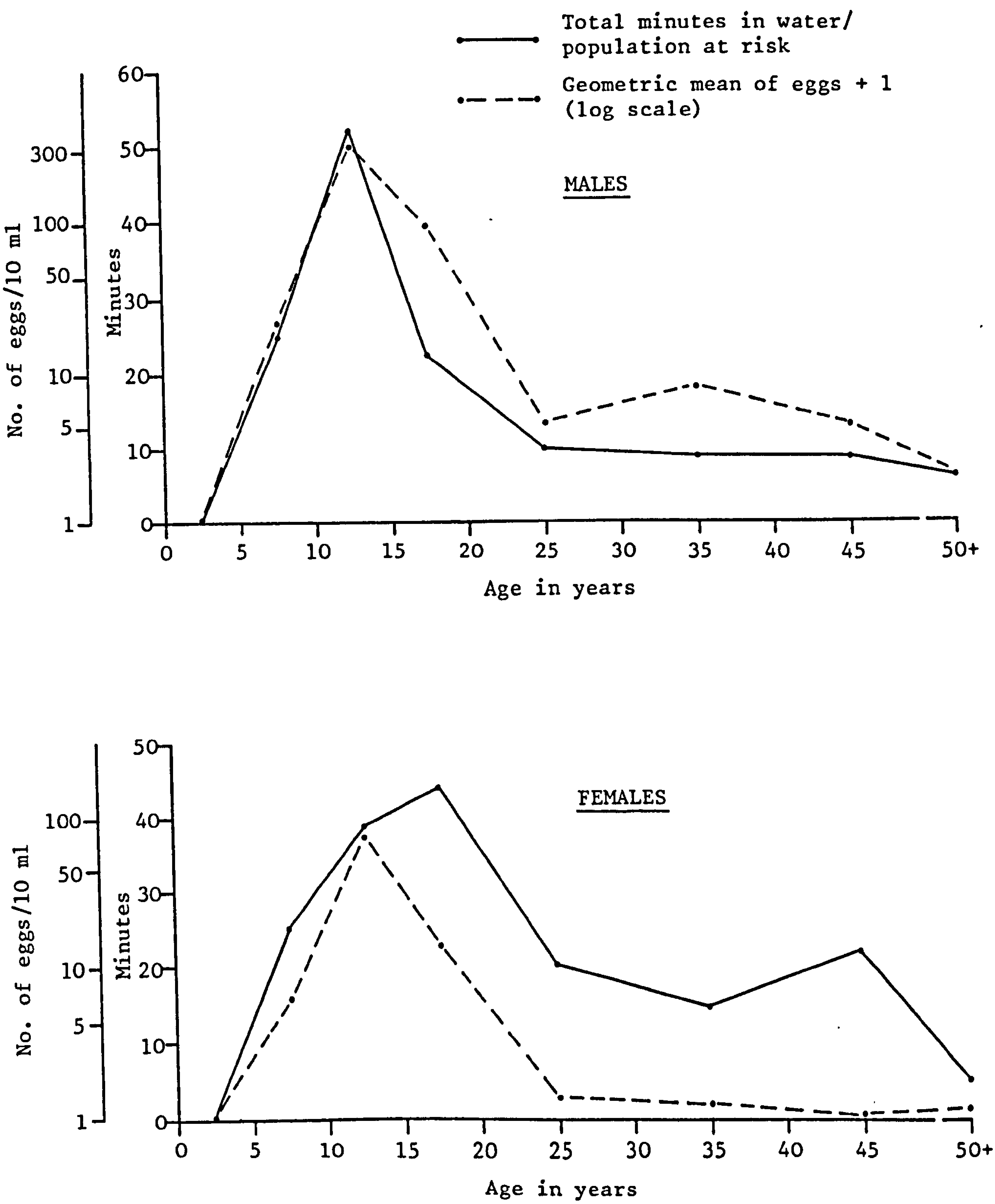

Fig. 44. Comparison of age-specific curves of geometric mean of egg counts + 1 per 10 ml among Agbenoxoe residents whose main point of water contact was WCP 4, and mean duration of water contact in WCP 4 by this population.

5. Observed urination in WCP 4

In 192 hours of observation comprising the sample of data analysed at WCP 4, only four different people were seen urinating into the WCP on 3 occasions.

Table 92. Details of those seen urinating in WCP 4.

Date	Hour	Sex	Age	Activity	*S. haematobium* eggs July 1979	*S. haematobium* eggs May 1980
12.1.80	15-16h	Male	10-14	Wading	5420	6964
7.5.80	17-18h	Male	5-9	Collecting water	32	320
21.6.80	17-18h	Fem.	5-9	Collecting water	0	0
21.6.80	17-18h	Fem.	5-9	Collecting water	0	0

While "oberver effect" could have reduced the true degree of urination in the water, the fragmentary information shown above tends to support the author's opinion that most urinary contamination in WCPs at Agbenoxoe was by children, and that boys were the main contributors of *S. haematobium* miracidia.

Discussion

The observations of human water contact at the farming village of Agbenoxoe differ in many respects from the earlier water contact observations by Dalton and Pole (1978) at the small, semi-nomadic fishing village of Fatem.

At Fatem, frequency and duration of water contact showed no seasonal variation, was significant among 0 - 4 year-old children, was highest for 5 - 9 year-olds, and greatest for males of all ages rather than females. There was also much more swimming, playing, and canoe-related activities at Fatem.

But despite expected differences in water contact patterns between the 2 different types of villages, there were similar findings. At Fatem, collecting water and washing accounted for the greatest overall percentage of water-contact frequency, but amounted to a much lower percentage-duration of water contact. Females engaged in the above domestic activities much more frequently than males. Greatest duration of male water contact per entry was in recreational and economic activities like swimming, playing, and washing in and around canoes. Lastly, a comparison of the geometric mean of positive egg counts with curves of mean duration of water contact at Fatem implied that, as at Agbenoxoe, rise and fall of male egg counts with age was more related to variation in mean duration of water contact (per group) than any influence of immunity; and as in Agbenoxoe females, comparison of the 2 curves indicated that egg output decreased faster with age than with reduction in water contact.

From their findings, Dalton and Pole (ibid) argued that installation of " a piped water supply would appear to be the most logical method of obviating lengthly lakeside domestic activities - especially that of fetching water ..."

But after 2 bore wells were installed at Fatem in 1975, there was no firm evidence to show this had any effect in lowering incidence of infection at the village through 1978, since chemotherapy and mollusciciding were also delivered to the village. The well water at Fatem was so hard that it was difficult to use for washing (unpublished report of sociology unit, WHO-0658 Project, 1977). It was mentioned earlier in this thesis (page 71) that both wells were non-functional by 1980.

The present finding at Agbenoxoe that fetching lake water is a relatively safe activity casts more doubt on the justification of installing bore-wells in lakeside villages to control the incidence of _S. haematobium_. If money were not a constraint, large, stable villages would benefit from a _properly-designed_ piped water supply, but in the author's opinion, mainly as protection against water-borne diseases other than _S. haematobium_.

CHAPTER 10

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

10.1 SUMMARY AND CONCLUSIONS

10.1.1 From snail sampling, November 1978 - June 1980

1. The overall rate of patent *S. haematobium* infections in 10,030 *B. rohlfsi* collected from 7 different lake sections was 11.95%. This was one of the highest snail infection rates ever recorded for a schistosome species over a broad endemic area. It also indicates that infection rates of *B. rohlfsi* have continued to rise since 1967. Earlier overall infection rates recorded at the lake were: 1.7%, 1967 - 1968 (Paperna, 1970); 7.6%, 1971 - 1972 (Jones, 1973); and 9.1% for the 2 most heavily-used WCPs in the WHO study area, 1973 - 1975 (Klumpp and Chu, 1977).

2. By 3 different methods of analysing the seasonality of transmission, 64 - 73% of yearly transmission potential existed in the high transmission season of December to March. This dropped to 23 - 31% in the low water season of April to July, and fell to 3 - 5% in the flood season of August to November. The current findings were basically similar to those from the WHO study area (1973 - 1975), indicating that the seasonality of *S. haematobium* transmission in the lake has remained stable.

3. The seasonality of transmission showed a consistent pattern in all 7 sampled lake sections where snails were found. In those villages without substantial growth of *Ceratophyllum* in the littoral zone, almost all yearly transmission potential was confined to December - March, while in the villages with the weed, high transmission potential often existed from December - June.

4. Of all *B. rohlfsi* collected, 42.3% were found on *Ceratophyllum*. In the April to July season, 73.8% were collected from the weed.

5. However, results from the 9 sampled villages in the Afram branch showed that if *Ceratophyllum* density became so thick that it decayed and caused water pollution, *S. haematobium* transmission was often interrupted.

6. During each lake season, highest numbers of infected snails were found in "pocket-shaped" WCPs, while far fewer were collected from "open beach" WCPs (existing mainly from March to July) and "channel - shaped" WCPs (existing mainly from August to December).

7. The most dangerous geographical location for S. haematobium transmission was in villages whose shores were at stream inlets or narrow coves. The safest locations were in villages at "exposed" shores, where the lake was many kilometres wide and usually without much weed growth.

10.1.2 From snail sampling and laboratory studies

1. The laboratory study on the growth, fecundity, and survivorship of B. rohlfsi at Agbenoxoe indicated the following:

   a. the species was able to maintain a high level of fecundity in mean water temperature that ranged between 28 - 30°C;

   b. the minimum egg to egg cycle from one generation to the next was 26 days;

   c. fecundity through the first 6 fortnights after snail hatching was greatest for snails raised in clear water, but survivorship and snail growth were consistently greatest for snails raised in water with a mud substratum;

   d. the intrinsic rate of natural increase (per fortnight) ranged from 1.096 for snails in lake water + mud + food to 1.642 for snails in lake water only + food. These values were high in comparison with recorded values for other intermediate hosts of schistosome species in different parts of the world, and indicate that Volta-Lake B. rohlfsi is an opportunistic species - able to populate an ecological niche very rapidly when conditions are favourable, but unable to maintain an equilibrium population for more than a few months.

2. The analysis of size and age-specific infection rates of S. haematobium in field-collected B. rohlfsi revealed the following:

   a. overall size-specific infection rates (patent infections) followed an "s-shaped" curve, ranging from 5 - 7% for B. rohlfsi between 3.0 - 4.5 mm shell height, to 30 - 55% for B. rohlfsi between 7.5 - 9.0 mm shell height.

b. when converted to intervals of snail age, the overall age-specific infection rates followed a more linear progression of increase with age, but the shapes of all curves implied that snail mortality caused by patent S. haematobium cercariae was high for snails between 2 and 5 weeks of age;

c. a mathematical model to quantify the rates at which B. rohlfsi naturally gained and lost S. haematobium cercariae in sampled villages indicated that the weekly rate at which they gained the infection was 5 % per week overall, 6.1% in the high transmission season, and 3.0% in the low transmission season.

10.1.3 From prevalence/intensity surveys around the lake

1. For the first time, the Nuclepore technique of urine examination for S. haematobium was used in a large-scale field survey. The technique was simple, rapid, and quantitative, and compared favourably with the established technique used in the WHO project.

2. S. haematobium prevalence rates and levels of egg output were extremely high in all villages surveyed in the Afram and Obosum sections of the lake. Levels of infection were lower in all other lake sections studied, but still constituted a public health problem in most villages in the Dayi, Mid Volta, Pru, Black Volta, and Oti sections. The only section where the infection was found to be very low (based on only one village) was at the Daka branch.

3. Levels of infection were highest in villages where Ceratophyllum grew and in villages that were situated along stream inlets or coves. Conversely, levels of infection were relatively low in villages that were located along shores exposed to wind and wave action.

4. Over 90% of the potential contamination of S. haematobium eggs was calculated to have come from 5 - 19 year-old children.

5. Application of catalytic models to the overall age-specific prevalence rate from sampled villages led to a prediction that the overall incidence rate was approximately 31% per year for 5 - 19 year-olds and 12% for 0 - 4 year-olds.

6. A comparison of present findings on prevalence rates among 5 - 14 year-old children in 15 sampled villages with an earlier survey on prevalence rates for the same age group in the same villages between 1970 and 1973 (Jones, 1973) provides evidence that levels of *S. haematobium* infection have continued to increase in most lake sections.

10.1.4 From research at Agbenoxoe

1. The distribution of *S. haematobium* infection in the village was focal, with highest levels among people on the west side of the village, who had most frequent water contact in WCP 4, where most infected snails were found.

2. Prevalence rates and egg counts were much higher for males than females in almost all age groups.

3. Although age-specific prevalence rates remained stable from the first to the second year of study, there were significant changes in egg output in some age groups. The latter changes could have been due to the fact that the second survey was conducted 2 months after the end of the observed high transmission period in 1980 while the first survey was conducted 4 - 5 months after the end of the observed high transmission period in 1979.

4. The age-specific prevalence curve for the village indicated that *S. haematobium* infection in the village was mainly confined to 8 - 17 year-old children. Prevalence rates were under 30% for all people over 19 years, and this was attributed to reduced water contact by the latter group, rather than any effect of immunity.

5. Highest prevalence rates and egg counts were recorded in 8 - 18 year-old boys. Only this group engaged frequently in the long-lasting activity of wading or playing. Very low prevalence rates and egg counts were recorded for adult females. Although they made more frequent trips to the lake than adult males per population at risk, their main activity was collecting water, and this activity was so short-lived per trip that it did not appear to offer much risk for *S. haematobium* infection.

6. Total frequency and duration of water contact increased each month during the dry season and dropped sharply at the onset of the rainy season. This period of maximum water contact coincided with most of the high transmission season as detected by snail sampling.

7. Greatest frequency of water contact during the day occurred in 2 peaks: from 06 - 07 h, and a larger peak from 16 - 18 h. Longest mean duration of water contact per entry was from 12 - 14 h, also the period of maximum shedding by *B. rohlfsi* of *S. haematobium* cercariae.

8. From the incidence study among the cohort of children, the rate per year was under 6% for 0 - 4 year-olds, increased to 29% for 5 - 9 year-olds, and was 32% in 10 - 14 year-olds.

9. Highest incidence rates were recorded in the period of year that coincided with the high transmission season as detected by snail sampling. Conversely, incidence rates were lowest in the months when infected snails were scarce.

10. While infected *B. rohlfsi* could be found along most of the village shore, the overall number of infected specimens per metre of shoreline sampled was 4 times higher inside of WCPs than outside of them. Moreover, water contact was generally insignificant outside of WCPs.

10.2 RECOMMENDATIONS FOR CONTROLLING *S. HAEMATOBIUM* AT THE VOLTA LAKE

10.2.1 Public health

Detailed recommendations for controlling the infection at the lake were given to the Government of Ghana by WHO in the final project report of 1979. From the author's observations of how work was conducted in the WHO project, and from the present research, the following public health recommendations may be added.

1. Metrifonate, such a cheap and effective drug against S. haematobium, should be made available to all health clinics and hospitals around the lake. The World Health Organization should assist the Ghana Ministry of Health in meeting the cost of the drug, if not directly, at least with advice on how to receive financial help from other donor agencies.

2. If in adequate supply in the above facilities, people living around the lake should be made aware of the drug's availability. Personnel in the health clinics and hospitals should be trained on how to quickly screen infected persons and how to safely administer the drug.

3. If and when resources are adequate to extend control of S. haematobium outside of the former WHO project and comparison areas, top priority should be given to treating infected people in all major villages throughout the Afram branch, on both shores, followed by extension to the Obosum branch.

4. Any form of selective population chemotherapy or targeted mass chemotherapy in villages of high transmission (e.g., in the Obosum branch) would have to be supplemented with a programme of focal mollusciciding every month or thrice every two months, from at least November to June if control of S. haematobium is the objective. Experience from the WHO project has shown that without such mollusciciding in a high transmission area, S. haematobium prevalence rates will remain unacceptably high because transmission will remain high.

5. However, if the objective is morbidity control, a programme of selective population chemotherapy or mass chemotherapy directed at the 5 - 19 year-old population once a year might be cost/effective without supplementary mollusciciding, even in high transmission areas of the lake.

6. In any chemotherapy campaign, prior screening of persons for *S. haematobium* infection should be as simple and rapid as possible, and performed in the field. The Ghana Ministry of Health should experiment more with haemoglobin-sensitive urine strips or dip-sticks for qualitative determination of *S. haematobium*. Although proved an ideal quantitative technique in the present research, single-use Nuclepore filters would be too expensive for large-scale application in Ghana, and cellulose-base filters require too much time and manpower to be practical.

7. If treatment is to be extended to adults during chemotherapy campaigns, such teams should visit the villages during evening hours. Experience in the WHO project showed that participation levels will be low if treatment is offered only during morning and afternoon hours. Treatment in the evening hours would also allow for health education advice, and might minimize side effects of metrifonate (allowing for a full night's rest while the drug's cholinesterase-inhibiting effect is most pronounced).

8. Water supply in the form of bore wells was a failure within one year after the end of the WHO project in Ghana. Such wells should never be installed in small semi-nomadic fishing villages. Priority should be given to supply piped water in all lakeside villages of over 1000 people. This was the original intention of the Volta River Authority (for all resettlement communities), but the plan never became reality. But with hundreds of bore wells being drilled each year in northern Ghana alone, there should be no great problem in extending this programme to the large Volta-Lake villages. Wells would be most cost/effective in those resettlement villages located over 2 km from the lake.

9. At present in Ghana, little or no effort is being devoted to health education as a means of reducing S. haematobium transmission. Recognizing the limited resources available to the Ghana Ministry of Health, it would nevertheless be desirable if a trial project could be initiated in at least one large lakeside village of moderate to high transmission that would take the following basic format: (1) snail sampling every month for pre- and postcontrol comparison of transmission potential; (2) selective population chemotherapy to be delivered one year after the start of snail sampling; (3) after chemotherapy, teaching of all primary and middle school children about S. haematobium and how transmission can be stopped by not urinating in the water (encouraging them to urinate on land before entering the lake; and educating the adults in the same way in special meetings; (4) organizing the villagers in a self-help programme to remove all emergent weeds from the drawdown area a few weeks before lake rise (the timing always known by lakeside residents), and then keeping the shore free of weeds thereafter, and the littoral zone free of Ceratophyllum; (5) encouraging the planting of vegetables across the drawdown area during lake regression to reduce foreshore weed growth (but not planting cassava where the stalks could be inundated); and (6) to evaluate the programme with postcontrol urine examination.

10. In retrospect, a big mistake was made in Ghana in allowing unchecked human settlement around the Volta Lake. The present research has shown that if lakeside villages had been situated at sites where the expanse of water was wide - away from stream inlets and coves - transmission of S. haematobium would have been kept at a relatively low level without further intervention. The mistake of allowing human settlement along narrow inlets and coves should not be repeated in future man-made lakes.

10.2.2 Academic

In the past, virtually no research has been conducted at Ghana's 3 universities on the biology and ecology of *B. rohlfsi*. Adequate facilities already exist in these institutions to carry out such research, and it would be desirable if Ghanaian lecturers and graduate students could explore the following research topics.

1. The effect of other parasites on *B. rohlfsi*, either in killing the snail or in preventing development of *S. haematobium* cercariae.

2. The effect of introducing ampullarid snails in competition with *B. rohlfsi*, as a facultative predator of *B. rohlfsi* eggs, and as a decoy to *S. haematobium* miracidia.

3. Field growth rates and death rates of *B. rohlfsi* in different temperatures and ecological conditions.

4. Mortality rates in *B. rohlfsi* infected at different ages by fresh *S. haematobium* miracidia.

5. Using the information in 3 and 4 to test the validity of the author's transmission model.

6. The effect of slow-release molluscicides on *B. rohlfsi* (following-up work by Chu, 1976), and possible use of these molluscicides in Volta-Lake WCPs (e.g., attached to floats or buoys to prevent inundation by mud, and easily movable to follow the rise and fall of the lake).

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APPENDICES

APPENDIX A. FORM FOR RECORDING DATA FROM SNAIL SAMPLING

Village ____________

Date __________

Lake branch __________

WCP ________

Type ______

Shore width (m) _____

Density rank (0 - 3):

1. Emergent weeds _____

2. Ceratophyllum _____

Sketch of WCP with vegetation

Time	Collector	No.	Cer	Pol	Stick	Pas	Palm	Log	Lud	Alt	Mud	Other

Snail size	Tabulating No. snails	No. infected Patent	Pre-p.	Xiph.	Other	Total snails	Patent cer.	Pre cer.
3.0								
3.5								
4.0								
4.5								
5.0								
5.5								
6.0								
6.5								
7.0								
7.5								
8.0								
8.5								
9.0								
10.0								
10.5								
11.0								
11.5								
12.0								
					TOTAL			

APPENDIX B. COMPUTER PROGRAMME FOR TRANSMISSION MODEL

```
5 REM **** SNAILS ****
10 DATA1,.971,.959,.943,.923,.898,.866,.829,.786,.736,.682,.624
20 DATA.562,.5,.438,.376,.318,.264,.214,.160,.122,.079
30 DIMM(22)
40 PRINT"⊃SNAIL PROGRAMME ... KLUMPP"
50 INPUT"ENTER FORCE OF INFECTION (TIME IN WEEKS)";A
70 INPUT"ENTER LAMBDA";L
72 INPUT"CONSTANT";B
75 OPEN4,4:CMD4
80 PRINT"T            P              I           U               TOT"
90 PRINT"------------------------------------------------------------------------"
110 FORT=1TO22
120 READM(T):NEXT
140 A=A/7
150 U=100
160 I=0
170 P=0
180 Q=I+U
185 T=0
190 PRINTT,P,I,U,Q
195 PRINT"------"
200 FORT=1TO2
210 U=U*M(T+1)/M(T)
215 Q=I+U
220 PRINTT,P,I,U,Q
221 PRINT"------"
225 NEXT
230 FORT=3TO21
240 S=(M(T)-M(T+1))/7
250 FORD=1TO7
260 Y=(M(T)-D*S)/(M(T)-(D-1)*S)
270 Z=Y↑L
275 IFT<6THENZ=Y↑(B*L)
280 I=U*Y*(1-EXP(-A))+I*Z
290 U=U*Y*EXP(-A)
300 NEXT
310 Q=I+U
320 P=I/Q
330 PRINTT,P,I,U,Q
335 PRINT"------"
340 NEXT
350 PRINT"************"
400 PRINT#4
410 CLOSE4
READY.
```

VILLAGE ______________ HOUSE NO. ______ DATE/TIME: 1st VISIT __________ 2nd VISIT __________ 3rd VISIT __________

PERSON'S NUMBER	PERSON'S NAME	POS	SEX	AGE	TRIBE	HOME TOWN	YRS IN VILLAGE 0-1	1-5	5+	OCCUPATION	NUMBER EGGS	ML URINE P	I	ATTENDANCE 1st	2nd	3rd

APPENDIX C. FORM FOR RECORDING DEMOGRAPHIC AND EPIDEMIOLOGICAL DATA (BY HOUSEHOLD)

HOUSE NO. ________ WCP (Dec-Mar): 1st ______ 2nd ________ WCP (Apr-Jul): 1st ______ 2nd ________ WCP (Aug-Nov) 1st _____ 2nd _____

Person's No.	Person's name	Rel	Sex	Age	EGG COUNTS Survey 1	EGG COUNTS Survey 2	Kg Weight (June)	Drug dose	Treatment dates 1	Treatment dates 2	Treatment dates 3	Reactions

APPENDIX D. SUMMARY FORM OF EGG COUNTS AND TREATMENT RECORD AT AGBENOXOE

Research
Recherche

Bulletin of the World Health Organization, 59 (4): 549-554 (1981)

Results of three years of cercarial transmission control in the Volta Lake*

K. Y. CHU,[1] R. K. KLUMPP,[2] & D. Y. KOFI[3]

After three years of cercarial transmission control using focal application of niclosamide and weed removal in water contact sites (WCSs) in the project area of the Volta Lake, the numbers of WCSs infested with cercariae and infected snails were reduced by over 90% in areas of both high and low endemicity. This, combined with selective population chemotherapy, reduced the prevalence of Schistosoma haematobium *infection by 72% in the area of low endemicity and 40% in the area of high endemicity. The intensity of infection in the villages was reduced by 78% in both areas. The overall annual cost of the cercarial transmission control programme was US $1.09* per capita.

A WHO/UNDP project was established in 1971 to study the epidemiology of schistosomiasis in the area of the man-made Volta Lake, Ghana, and to investigate methods for controlling the disease. The intermediate host of *Schistosoma haematobium* in the lake is *Bulinus rohlfsi.* Schistosome-infected snails are almost exclusively confined to human water contact sites (WCSs) (*1*), and within these sites are concentrated near the shore (*2*). The levels of cercarial (*3*) and miracidial transmission (*4*) are determined by the shape of the WCS within emergent vegetation, and the type and density of this vegetation, which, in turn, are determined by the seasonal level of the lake. The main transmission season occurs during the first few months of the year when the lake begins its annual phase of drawdown. During this period, pocket-shaped WCSs form an ideal environment for expanding snail populations and high numbers of infected snails are found. During the low water phase, transmission occurs only in WCSs where the submerged weed, *Ceratophyllum demersum*, grows (*3, 5*).

Preliminary trials of focal mollusciciding and *Ceratophyllum* removal were carried out to test and assess the transmission control methods developed (*6*), after which the campaign was extended to the whole project area in May 1975. Chemotherapy was begun later in that year.

The present report describes the results of three years of schistosome transmission control in the Volta Lake, and presents a cost analysis of this selective snail control programme.

PROJECT AREA

The project area is located on the Pawmpawm branch and the south-east section of the Afram branch of the Volta Lake and comprises 26 villages or "study units" (Fig. 1). Ecologically, the project area can be divided into two sections: 12 villages on the Afram branch, an area of high endemicity, and 14 villages of lower endemicity on the Pawmpawm branch. The Afram branch contains moderate to heavy growths of *Ceratophyllum* and transmission of the disease can occur throughout the year. The Pawmpawm branch villages (study units 1–14) are now

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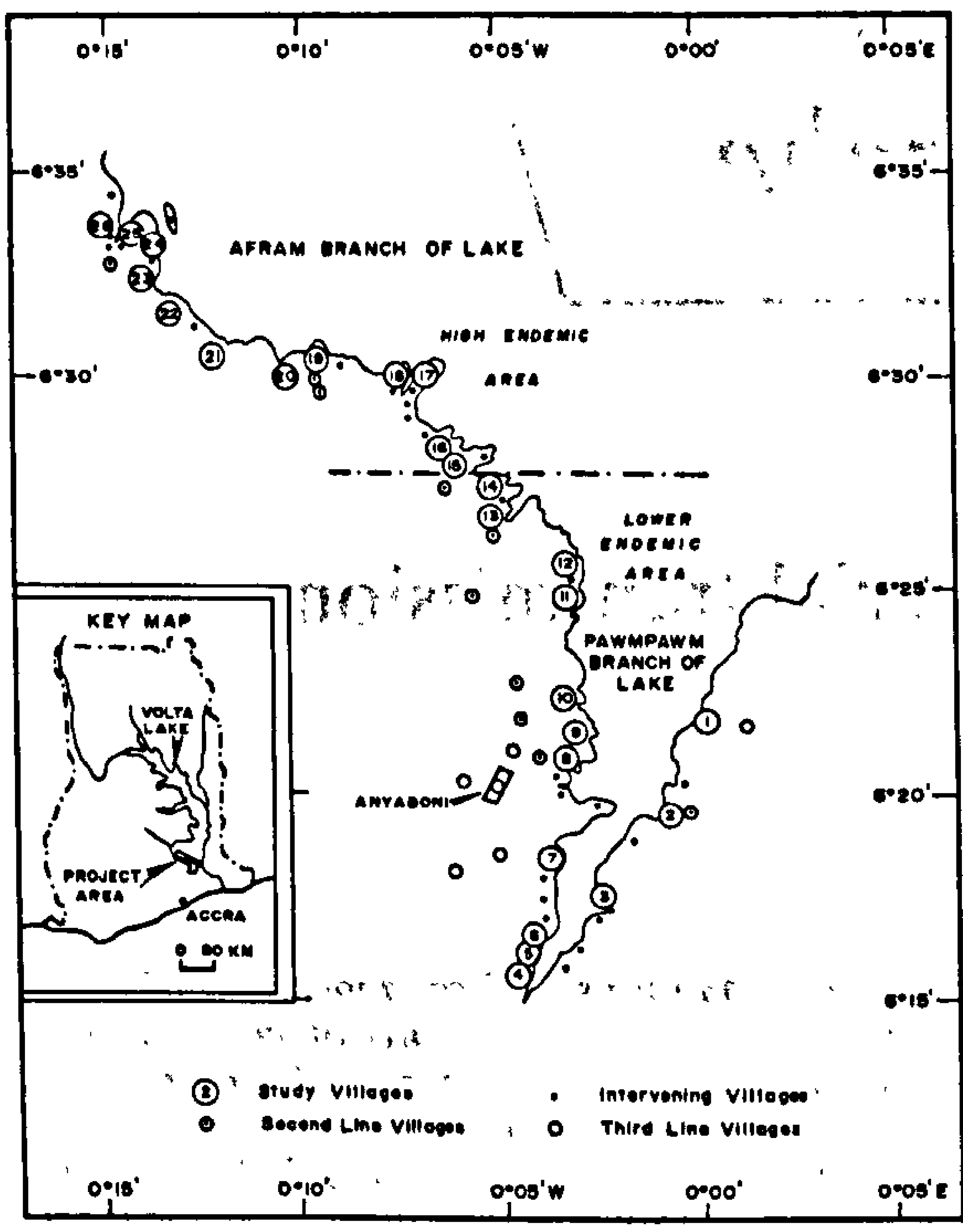

Fig. 1. The project area of the Volta Lake.

largely devoid of the weed and transmission is limited to the first 2–4 months of the year.

Approximately 7500 people in the study area and intervening villages, plus a further 7500 inhabitants of the hinterland communities who use the lake as a source of water, are exposed to schistosomiasis.

MATERIALS AND METHODS

About 230 water contact sites were in regular use in the 26 study villages, an average of 8–9 per village. From May 1975, monthly visits were made to each WCS in the villages of lower endemicity while the important WCSs in the Afram branch were visited once every 2–3 weeks.

Each WCS was classified according to its ecological type, the type and amount of vegetation, the degree of human water contact, snail density, and the presence of infected snails. The two latter criteria had also been assessed by pre-intervention sampling of the site. Scattered *Ceratophyllum* in a habitat was removed using rakes. If treatment was necessary, a niclosamide molluscicide (containing 70% active ingredient) was applied at a calculated concentration of 0.5–1.0 mg/litre with a hand sprayer. When it was found necessary to spray an open beach type of WCS where the scattered *Ceratophyllum* were more difficult to remove, a

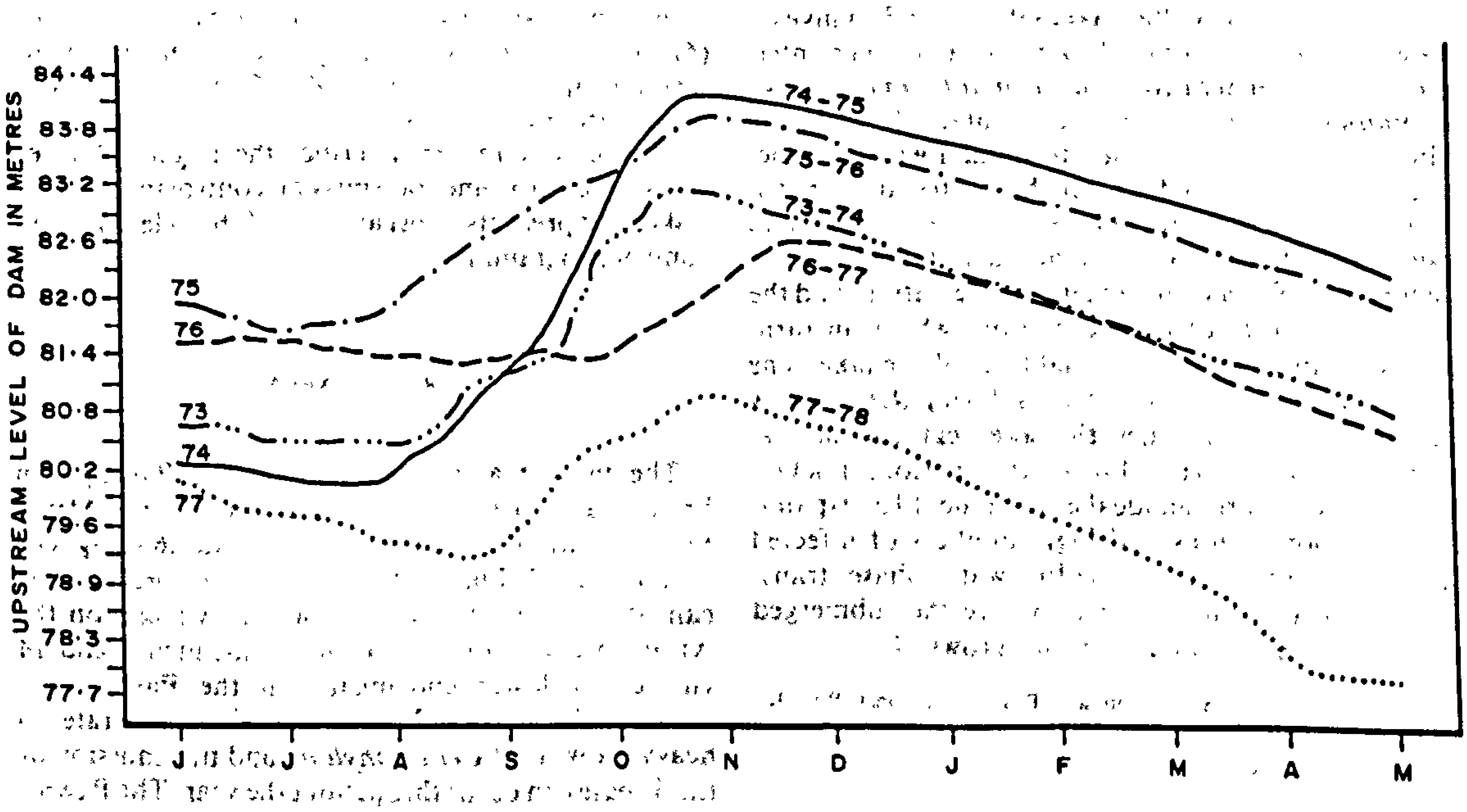

Fig. 2. Fluctuations in the lake water level between 1973 and 1978.

plastic curtain was set in the water to cordon off the treated area from the open lake. Details of this work are presented elsewhere (*6*).

For the assessment of control efforts, snail samples were taken each month from 33 WCSs in 10 villages of low endemicity and 16 WCSs in 6 villages of high endemicity, using palm-leaf mats and the modified man-time method (*3*). Other sites were checked occasionally. A WCS was considered positive if any snail was found to be infected with mature *S. haematobium* cercariae.

Because there was considerable inter-village movement, it soon became apparent that people in the study unit villages could become infected in the intervening villages where no mollusciciding had been conducted. Therefore, from June 1977, the most important WCSs in the intervening villages were also treated with molluscicide on a monthly basis, and sampled for infected *B. rohlfsi* from time to time.

To assess the combined effect of chemotherapy and transmission control, an epidemiological index was defined as the product of the disease prevalence rate in man and the geometric mean number of *S. haematobium* eggs per 5 ml of positive urine, divided by 100. This epidemiological data was taken from project records.

RESULTS

Ecological changes

Fluctuations in the lake water level during the period 1973–78 are shown in Fig. 2. The peak level occurred in late 1974 when some lakeside compounds at Akokoma, Kwabia, Asakeso, and Akotui West were flooded, leading to the abandonment of some WCSs and the creation of new ones. Since 1975, the lake level has dropped each year.

Table 1. Proportion of cercaria-infested WCSs and infected *B. rohlfsi* found in monthly surveys in the area of low endemicity 1973–78. Percentages are given in parentheses.

	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	Total
Pre-intervention													
1973–74													
WCS	1/25 (4.0)	0/25 (0)	2/25 (8.0)	0/25 (0)	1/25 (4.0)	4/25 (16.0)	4/25 (16.0)	10/33 (30.3)	5/33 (15.15)	6/33 (18.18)	2/33 (6.06)	0/33 (0)	35/340 (10.29)
Snails	1/106 (0.94)	0/190 (0)	3/59 (5.08)	0/1 (0)	1/37 (2.7)	6/102 (5.88)	19/152 (12.5)	26/213 (12.21)	11/147 (7.48)	13/93 (13.98)	3/84 (3.57)	0/87 (0)	83/1271 (6.53)
1974–75													
WCS	1/33 (3.03)	2/33 (6.06)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	3/33 (9.09)	2/33 (6.06)	3/33 (9.09)	5/33 (15.15)	3/33 (9.09)	1/33 (3.03)	20/396 (5.05)
Snails	1/38 (2.63)	3/26 (11.54)	0/20 (0)	0/31 (0)	0/20 (0)	0/39 (0)	3/61 (4.92)	6/81 (7.41)	4/170 (2.35)	16/110 (14.55)	4/96 (4.17)	1/36 (2.78)	38/728 (5.22)
Post-intervention													
1975–76													
WCS	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	1/33 (3.03)	0/33 (0)	0/33 (0)	1/33 (3.03)	2/396 (0.51)
Snails	0/10 (0)	0/5 (0)	0 (0)	0/3 (0)	0/7 (0)	0/19 (0)	0/39 (0)	0/22 (0)	5/38 (13.16)	0/4 (0)	0/4 (0)	1/30 (3.33)	6/181 (3.31)
1976–77													
WCS	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	1/33 (3.03)	0/33 (0)	0/33 (0)	0/33 (0)	1/396 (0.25)
Snails	0/2 (0)	0/2 (0)	0/1 (0)	0 (0)	0 (0)	0/2 (0)	0/11 (0)	0/17 (0)	1/44 (2.27)	0/34 (0)	0/3 (0)	0/1 (0)	1/117 (0.85)
1977–78													
WCS	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	1/33 (3.03)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	0/33 (0)	1/396 (0.25)
Snails	0 (0)	0/18 (0)	0 (0)	0/3 (0)	0 (0)	1/1 (100.0)	0/20 (0)	0/27 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1/69 (1.45)

As the water level fell, the number of snail-bearing *Ceratophyllum* in the Pawmpawm branch of the lake also dropped (*5*). Therefore, cercarial transmission in this area decreased naturally in the year before intervention began and has remained at a low level. The weed has now completely disappeared from the lake at all the lakeside villages up to study unit 16.

Effects of transmission control

Tables 1 and 2 show the number of snails with mature infections and the number of cercaria-infested WCSs in the areas of low and high endemicity between 1973 and 1978. In the area of low endemicity, natural reductions in these parameters in 1974 were due to the disappearance of *Ceratophyllum* (*5*). Similar reductions in the area of high endemicity during the same year were mainly caused by the flooding of the lake at Asakeso and Akotui West, which forced people to move away from the WCSs.

In the first year of intervention, the number of positive WCSs was reduced by 90% in the area of low endemicity, and by 83% in the area of high endemicity. After three years, reductions of 95% and 96%, respectively, had been achieved. The numbers of infected snails were similarly reduced to 3% and 1% of pre-intervention levels in areas of low and high endemicity, respectively, after three years of transmission control.

Table 3 presents the prevalence and intensity of infection in the villagers after three years of control measures. There was a large drop in epidemiological index in each village, which paralleled the percentage reduction in the numbers of infected snails during the same period.

Cost analysis

The mean annual cost of the selective snail control programme amounted to 3.00 Cedis (₵) or $1.09 *per*

Table 2. Proportion of cercaria-infested WCSs and *B. rohlfsi* found in monthly surveys in the area of high endemicity 1973–78. Percentages are given in parentheses.

	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	Total
Pre-intervention													
1973–74													
WCS	3/7 (42.86)	3/7 (42.86)	2/7 (28.57)	1/7 (14.29)	1/7 (14.29)	4/7 (57.14)	5/7 (71.43)	11/16 (68.75)	7/16 (43.75)	7/16 (43.75)	7/16 (43.75)	3/16 (18.75)	54/129 (41.86)
Snails	8/195 (4.1)	15/138 (10.87)	16/109 (14.68)	2/26 (7.69)	1/45 (2.22)	13/85 (15.29)	18/138 (13.04)	63/271 (23.25)	53/322 (16.46)	19/204 (9.31)	17/110 (15.45)	3/103 (2.91)	228/1746 (13.06)
1974–75													
WCS	2/16 (12.5)	5/16 (31.25)	4/16 (25.0)	1/16 (6.25)	0/16 (0)	0/16 (0)	2/16 (12.50)	8/16 (50.0)	8/16 (50.0)	6/16 (37.5)	6/16 (37.5)	6/16 (37.5)	48/192 (25.0)
Snails	5/94 (5.32)	15/202 (7.43)	7/101 (6.93)	1/20 (5.0)	0/28 (0)	0/68 (0)	8/95 (8.42)	56/774 (7.24)	37/495 (7.47)	21/241 (8.71)	7/70 (10.0)	9/98 (9.18)	166/2286 (7.26)
Post-intervention													
1975–76													
WCS	0/16 (0)	1/16 (6.25)	0/16 (0)	0/16 (0)	0/16 (0)	1/16 (6.25)	0/16 (0)	3/16 (18.75)	0/16 (0)	1/16 (6.25)	1/16 (6.25)	1/16 (6.25)	8/192 (4.17)
Snails	0/32 (0)	1/59 (1.69)	0/28 (0)	0/20 (0)	0/4 (0)	1/27 (3.7)	0/29 (0)	3/67 (4.48)	0/60 (0)	1/21 (4.76)	1/36 (2.78)	1/55 (1.82)	8/438 (1.83)
1976–77													
WCS	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	1/16 (6.25)	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	1/16 (6.25)	0/16 (0)	0/16 (0)	2/192 (1.04)
Snails	0/32 (0)	0/71 (0)	0/103 (0)	0/94 (0)	1/14 (7.14)	0/2 (0)	0/3 (0)	0/7 (0)	0/48 (0)	1/78 (1.28)	0/59 (0)	0/68 (0)	2/579 (0.35)
1977–78													
WCS	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	0/16 (0)	1/16 (6.25)	1/16 (6.25)	0/16 (0)	0/16 (0)	2/192 (1.04)
Snails	0/56 (0)	0/59 (0)	0/65 (0)	0/14 (0)	0/8 (0)	0/8 (0)	0/17 (0)	0/79 (0)	1/48 (2.08)	1/22 (4.55)	0/16 (0)	0/27 (0)	2/419 (0.48)

Table 3. Prevalence of schistosomiasis and egg output per 5 ml of positive urine in the 26 study villages before and after three years of control measures

Level of endemicity	Disease prevalence (%) (p)			Geometric mean egg output (per 5 ml of urine) (d)			Epidemiological index (p x d)/100		
	1974	1978	reduction (%)	1974	1978	reduction (%)	1974	1978	reduction (%)
Low	64.6	17.9	72.3	33.1	7.1	78.5	21.4	1.3	94.1
High	83.9	50.7	39.6	65.4	14.0	78.6	54.9	7.1	87.1

capita for the total population covered of 15 000. Personnel costs represented 32%, transportation 42%, and molluscicide 25% of the total. The evaluation team cost ₵2.26 or $0.82 *per capita* annually, giving a total annual cost for the combined teams of ₵5.26 or $1.91 *per capita.*

DISCUSSION

The feasibility of cercarial transmission control by focal intervention measures in a large man-made lake has been demonstrated in this project. A selective snail control programme was carried out, in which mollusciciding and weed clearance were concentrated on the most dangerous transmission sites. In the area of low endemicity, less intervention work was done and interruption of transmission was greatly aided by the natural disappearance of the snail indicator weed, *Ceratophyllum*, just before the intervention period (*5*). In the area of high endemicity, intensive intervention work was conducted but interruption of transmission was severely hampered by a significant increase in *Ceratophyllum* near shore. The weed was always present in the deep stream inlets of the lake in this area, and the progressive drop in the lake water level simply shifted these deep water *Ceratophyllum* masses into shallow water. Nevertheless, local transmission was substantially reduced in the area by focal mollusciciding of the most dangerous village WCSs 3 times every two months, and of the remaining sites at monthly intervals, supplemented when appropriate by weed removal.

It is of interest to note the different results in the areas of low and high endemicity (Table 3). In the former, the pre-intervention disease prevalence of 64.6% was reduced to 17.9%, a drop of 72.3%, while in the latter, the prevalence was reduced from 83.9% to 50.7%, a drop of 39.6%. However, the percentage reduction in the intensity of infection was equal in both endemic areas, as shown by a drop of 78.5% in the geometric mean egg density in urine samples. This indicates that cercarial transmission control was equally effective in both endemic areas.

During the project, it was found that the combined intervention effort had to be extended beyond the original project area villages, to cover intervening villages, as well as villages up to 5 km away from the lake. Inhabitants of these hinterland areas depended solely on the lake for their water during most of the year, including the high transmission season, and also used the lake for washing and bathing throughout the year. They would thus have benefited most from a water supply programme.

It is difficult to compare the costs of schistosomiasis control projects around the world, because of national and international inflation, methods of analysis, species of schistosome, level of disease, type of terrain, etc. However, the $1.09 *per capita* cost of mollusciciding and manual weed removal to control *S. haematobium* in the project area of the Volta Lake compares favourably with costs involved in other large-scale schistosomiasis projects, and is considerably lower than the $3.24 *per capita* cost reported in St Lucia for the control of *S. mansoni* by mollusciciding alone (*7*).

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RÉSUMÉ

RÉSULTATS DE TROIS ANS DE LUTTE CONTRE LA TRANSMISSION DES CERCAIRES DANS LE LAC VOLTA

Le programme de lutte contre la transmission des cercaires dans la région du Lac Volta a débuté en mai 1975 dans 26 villages constituant des unités d'étude. Cette intervention a nécessité l'application focale de niclosamide et l'élimination de *Ceratophyllum* dont sont parsemés certains habitats.

Dans les villages de faible endémicité, chaque lieu de contact avec l'eau a été visité une fois par mois (unités d'étude 1–14), tandis que dans les villages de forte endémicité (unités d'étude 15-26), les visites étaient portées à trois tous les deux mois. Un technicien travaillant sur le terrain décidait immédiatement de la question de savoir si un lieu de contact avec l'eau devait être traité et de quelle façon.

Au bout de trois ans, le nombre des lieux de contact avec l'eau infectieux et le nombre des mollusques infectés avaient diminué de plus de 90% tant dans les régions de forte endémicité que de faible endémicité. La lutte contre la transmission des cercaires, associée à une chimiothérapie sélective de la population, a fait régresser la proportion des infections par *Schistosoma haematobium* de 72% dans la région de faible endémicité et de 40% dans la région de forte endémicité. L'intensité de l'infection dans les villages a diminué de 78% dans l'une et l'autre régions.

Le coût global annuel du programme de lutte contre la transmission des cercaires s'est élevé à US $1,09 par habitant.

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Transmission dynamics of miracidia of *Schistosoma haematobium* in the Volta Lake*

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Schistosoma haematobium miracidia were detected in sentinel snails placed in 16 human water contact sites in the Volta Lake, each month from March 1973 to November 1977. Results showed that rates of infection were seasonal, and that infected snails were more often found in water contact sites sheltered by emergent plant growth than in exposed open beach sites with no emergent vegetation. Sentinel snail infection rates were correlated with natural snail infection rates and with epidemiological levels of schistosomiasis in village inhabitants. After two years of chemotherapy and mollusciciding, levels of disease and sentinel snail infection rates dropped in two-thirds of the villages. In the remaining villages, however, the sentinel snail infection rates were not correlated with the fall in epidemiological level, because of ecological changes in the water contact sites.

It is concluded that, unless control measures are continued, the constant changes in the lake shore environment will lead to a rapid re-establishment of previous levels of disease transmission.

The study of the transmission dynamics of schistosomiasis is essential to an understanding of the epidemiology of the infection. Increasing attention is being given to the dynamics of miracidia in the transmission cycle. Schistosome miracidia cannot be studied directly in natural waters, and the only way to monitor changes in miracidial density is to study infected snails. However, the constant fluctuation of natural snail populations precludes their use and the only practical approach is to expose fixed numbers of laboratory-bred (sentinel) snails in natural transmission sites at regular intervals. Such studies on *Schistosoma mansoni* in St Lucia have been reported by Upatham (*1–4*). This report presents the results of studies on the miracidial transmission of *S. haematobium*, which formed part of the WHO/UNDP Schistosomiasis Project on the Volta Lake, and which were intended to assess the effects of various factors, especially chemotherapy and mollusciciding.

MATERIALS AND METHODS

Snail breeding and rearing

Wild *Bulinus rohlfsi*, the intermediate host of *S. haematobium*, were collected from the Volta Lake. Five adult snails were placed in each of sixty 10-litre plastic bowls containing 6 litres of stream or lake water and kept in a shaded, airy room. Maximum water temperature ranged between 27 °C and 31 °C, and the water was changed every 2–3 days. The adult snails were allowed to lay eggs for a period of ten days, after which they were removed and the eggs left to hatch. Baby snails were fed tropical fish food or, in very hot weather, a mixture of fish food and dried lettuce powder. After two weeks of age, snails were fed only dried lettuce. Up to 50 snails could be raised in each plastic bowl.

Sentinel snail cage

The cages were copied from the design used in the Rockefeller Project in St Lucia (*1*), and were made of 2-mm mesh nylon screen, in the shape of an envelope, 10 x 15 cm. The edges of the cages were heat-sealed. A U-shaped piece of PVC tubing was used as an internal support. The cages were covered with a protective welded wire frame to prevent damage and thus improve sentinel snail survival.

Location of cages in the water

In an attempt to determine the most suitable location for sentinel snail cages, an experiment on the dispersal of miracidia was conducted in the field. An area of the lake away from human water contact sites was selected, where the water was 1 m deep. Cages were placed in concentric circles 1–2 m from a central

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point. One-third of the cages were suspended 10 cm below the water surface, one-third 50 cm deep, and the remainder 100 cm deep. Urine containing about 150 000 *S. haematobium* eggs was then poured into the water at the central point. The snails were collected from the lake 24 hours later, kept for 27 days, and crushed to examine for cercariae.

None of the snails kept at the 10 cm and 50 cm depths became infected, but 11 out of 68 (16.2%) placed at the lowest level were found to be positive. This result agrees with Shiff's finding (*5, 6*) that *S. haematobium* miracidia tend to be more concentrated near the bottom of shallow field water. It is possible that the eggs hatched close to the bottom cages and therefore miracidia were most concentrated there, while local water currents probably reduced the concentration at the higher levels. Hence, it was decided to place all sentinel snail cages near the bottom of the lake near shore during the monthly field surveys.

Determination of infection

It was initially intended to study the relationship between the number of daughter sporocysts and the number of successful miracidial penetrations of the sentinel snails. However, under field conditions, it was impossible to detect clearly the mother and daughter sporocysts. Different rates of maturation of the daughter sporocysts made examination tedious, and the number of abnormal or amorphic forms of daughter sporocysts (*7–9*) made it impossible to differentiate various types of trematode infection from *S. haematobium*. Assessment was therefore based simply on the presence of mature or immature schistosome cercariae upon crushing of the snails 30 days after retrieval from the lake.

Field studies

Two-month-old laboratory-bred *B. rohlfsi* were exposed each month in the main human water contact sites of 16 selected villages in the project area. In each village, 10 cages containing a total of 100 snails were placed in the water and left *in situ* for two days. After retrieval, the exposed snails were kept in the laboratory for 30 days before they were crushed and examined with a dissecting microscope for the presence of schistosome cercariae.

Data collection began in March 1973 in 8 villages and was extended to 16 villages during March and April 1974. Results obtained in this early period up to completion of the first round of selective population chemotherapy (SPC 1) in February 1976 were taken as baseline data. Two further rounds of chemotherapy were completed in 1976 and 1977, and data collected during this period should reflect the results of the campaign. No reliable data were obtained after November 1977, because of a lack of suitable snails.

The level of disease in the human population is expressed as an epidemiological index. This is defined as the product of the disease prevalence rate and the geometric mean of eggs counted in 5 ml samples of positive urine, divided by 100. The pre-intervention epidemiological indices were based on data collected in a survey of all 26 villages in 1974. The post-intervention parasitological surveys were carried out 6–10 months after the start of SPC 1 and 4–9 months after SPC 2.

Monthly sampling of field snails was also conducted in 14 of the 16 WCSs used for sentinel snail exposures. Snails were collected by the palm-mat sampling method in 8 villages and by the modified man-time method, using dip-nets, in 6 villages (*10*). All snails collected were brought back to the field laboratory and examined for both mature and immature cercariae. As in the sentinel snail programme, the pre-intervention baseline data period was from March 1973 to May 1975, when intervention by focal mollusciciding was started in all suitable WCSs.[a]

RESULTS

Seasonal variations

The pre-intervention baseline data for the monthly sentinel snail infection rates and the annual lake water level fluctuation, between March 1973 and February 1976, are shown in Fig. 1. Infection rates were found to be seasonal, with high rates at periods of high water level and low rates at periods of low water level.

[a] The mollusciciding programme did not affect the sentinel snail programme, since cages were always retrieved before the monthly spraying with niclosamide. Molluscicidal action in a WCS was short-lived and there was no residual effect because the WCSs shifted continually with the rise and fall in the water level.

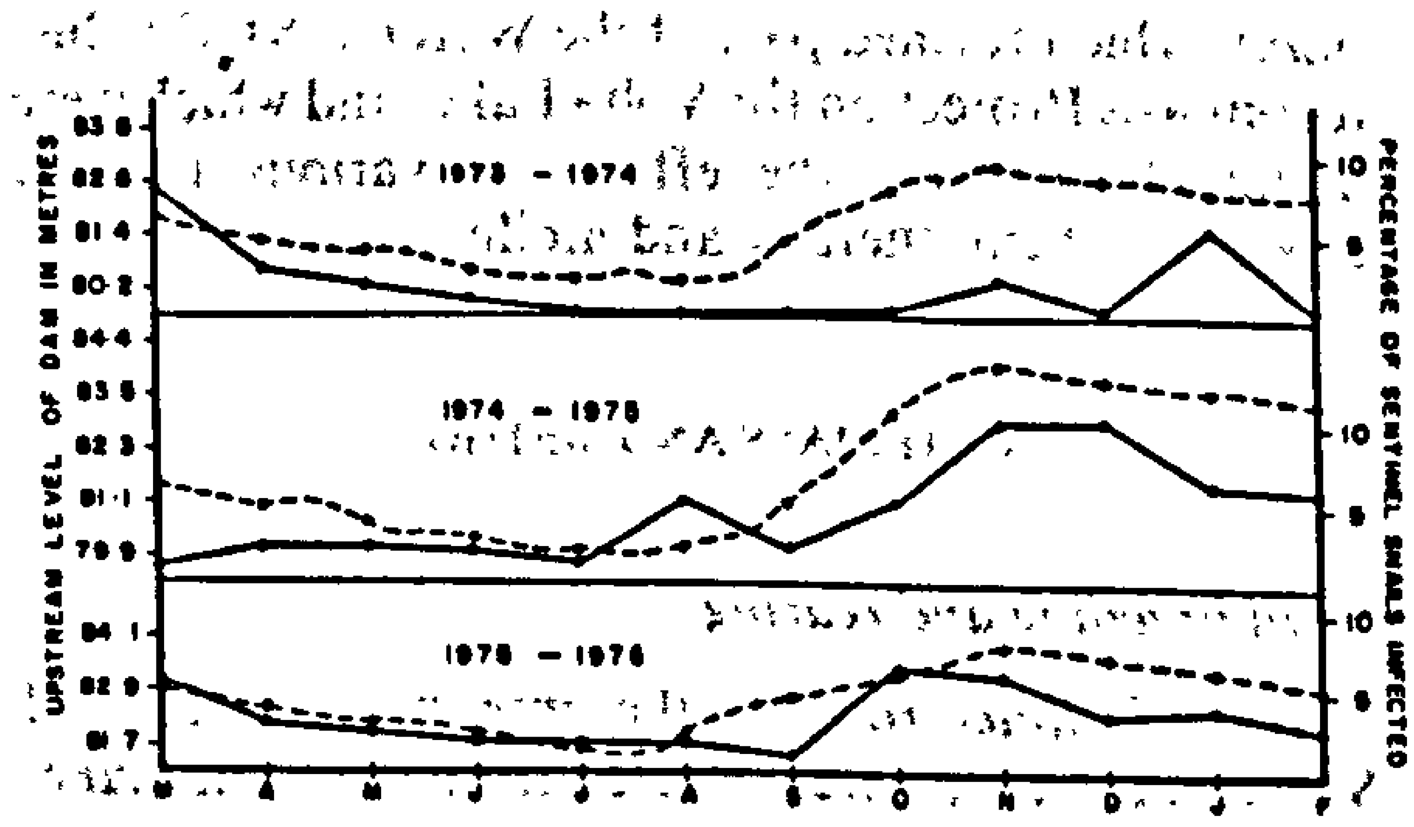

Fig. 1. Water level fluctuations (dashed line) and sentinel snail infection rates in water contact sites (solid line), in the Volta Lake, 1973–76.

Table 1. Number of water contact sites found positive in monthly sentinel snail exposures, 1973–76

Type of WCS	March 1973–February 1974		March 1974–February 1975		March 1975–February 1976		Total	
	No. positive/No. tested	%	No. positive/No. tested	%	No. positive/No. tested	%	No. positive/No. tested	%
Open beach	11/42	26.2	35/65	53.8	24/75	32.0	70/182	38.5
Pocket	14/31	45.2	45/60	75.0	33/55	60.0	92/146	63.0
Channel	7/23	30.4	18/34	52.9	18/35	51.4	43/ 92	46.7

Ecological types of WCS

Water contact sites in the lake were subject to change because of the annual cycle of water level fluctuation (*10*). Three main types of WCS were observed: open beaches, pockets, and channels. Open beach sites were most common at low water level and were found on wide exposed stretches of shoreline where little or no emergent vegetation grew in the water. Channel-shaped sites, mainly cut through dense *Polygonum senagalense* from the shore to the open water, started to appear in late August when the water level began to rise, and predominated from high water level to the early drawdown phase. Pocket-shaped WCSs were also numerous at high water level and early to mid-drawdown, i.e., from September to March. Details of the formation of such WCSs are described elsewhere (*10*).

If any sentinel snails became positive after exposure in a WCS, that site was considered positive for miracidial transmission. Table 1 shows the number of times each WCS was positive between 1973 and 1976, grouped according to the type of site. Over the three-year period, the number of sentinel snail infections in pocket-shaped WCSs was significantly higher than that in channel-shaped sites ($\chi^2 = 6.09$, $P<0.05$). There was no significant difference in infection rates between channel-shaped and open beach WCSs ($\chi^2 = 1.73$, $0.1<P<0.2$).

Natural snail populations

In the main WCSs used for both sentinel snail exposures and ecological snail sampling, the highest numbers of field *B. rohlfsi* and of infected specimens were found in January, February, and March. Few snails were found in September and October because of the rapidly rising water level. At lowest water levels (April–July), *B. rohlfsi* were found almost exclusively in WCSs with moderate to heavy growths of *Ceratophyllum*.

From Fig. 1, it can be seen that peak sentinel snail infection rates occurred in March 1973, January, November, and December 1974, and October and November 1975. Except for the latter two months, these peak transmission periods coincided with the peak periods of field snail infections.

Comparative results of sentinel snail and field snail infection rates in the WCSs of 14 villages from March 1973 to May 1975 are presented in Table 2. At Pawmpawmnya No. 1, on the steeper eastern shore of the lake, 2157 sentinel snails were examined and only 12 were positive, an infection rate of 0.56%. During 27 consecutive months of field snail sampling at the same site, only one snail was found (in December 1974 when the site was pocket-shaped in emergent vegetation for one month), and it was positive for cercariae. The epidemiological index of Pawmpawmnya No. 1 has always been low because the WCSs in the village have almost always been open beaches devoid of weed growth. If this atypical village is omitted from the analysis, infection rates of sentinel and field snails in the remaining 13 villages were significantly correlated ($r = 0.52$, $P<0.05$).

Epidemiological levels of schistosomiasis

The epidemiological indices of disease and the overall sentinel snail infection rates in all 16 villages before the completion of SPC1 are shown in Table 3. The snail infection rates were significantly correlated with the epidemiological indices of schistosomiasis in the villages ($r = 0.79$, $P<0.01$).

Effects of intervention

Table 4 shows the sentinel snail infection rates before completion of SPC 1 and the post-intervention data collected after completion of SPC 1 and SPC 2. Of 16 villages studied, a significant reduction in miracidial transmission occurred in 9 villages following SPC 1 and in 11 villages after SPC 2. In the villages of Kasa and Asakeso, miracidial transmission rose following drug treatment because the villagers changed from their original WCS to a new, smaller one. In Pawmpawmnya 1, positive results were

Table 2. Sentinel and field snail infection rates in the water-contact sites of 14 villages, March 1973–May 1975

Village	Sentinel snails		Field snails	
	No. positive/No. tested	%	No. positive/No. tested	%
Pawmpawmnya No. 1[a]	12/2157	0.56	1/1	100.0
Fatem	97/2303	4.21	11/145	7.59
Kasa	95/2272	4.18	8/140	5.71
Poakwe Pawmpawmnya	32/2327	1.38	14/783	1.79
Dawa Kofi	55/1308	4.2	12/97	12.37
Akokoma	31/1107	2.8	1/71	1.41
Kwabia	64/2177	2.94	1/31	3.23
Kuma Kuma	91/2201	4.13	19/106	17.92
Asakeso	45/2146	2.1	16/457	3.5
Akotui West	113/2295	4.92	171/1518	11.26
Tamayeso	87/1068	8.15	4/49	8.16
Nyafutu	29/965	3.0	0/32	0
Dukuase	67/974	6.88	32/367	8.72
Odortom II	87/1165	7.47	35/330	10.61
Total	905/24 465	3.70	325/4127	7.87

[a] If results from Pawmpawmnya No. 1 are omitted, $r = 0.52$, $P<0.05$.

Table 3. Pre-intervention epidemiological index and sentinel snail infection rates in 16 villages, 1974–75

Village	Epidemiological index[a]	Snail infection rate (%)
Odortom II	72.26	7.88
Tamayeso	67.90	6.56
Akotui East	54.85	3.44
Dukuase	54.74	8.11
Akotui West	49.65	4.54
Nyafutu	47.13	2.58
Akrusu	42.26	7.82
Dawa Kofi	37.98	3.77
Fatem	31.91	3.39
Kasa	27.64	3.35
Poakwe Pawmpawmnya	25.00	1.14
Kwabia	23.94	2.52
Kuma Kuma	23.32	3.58
Asakeso	22.56	2.04
Akokoma	21.52	1.91
Pawmpawmnya No. 1	5.79	0.45

[a] Epidemiological index = disease prevalence x geometric mean egg count per 5 ml of urine/100.

obtained in only two of the 33 pre-intervention exposures, providing further evidence that transmission was low and sporadic. At Akotui East, the WCS used for the sentinel snail exposures was frequently pocket-shaped before the start of chemotherapy, but later became an open beach habitat because of the continuing drop in lake level during 1976 and 1977. No infected snails were found in this WCS after SPC 1, even though the epidemiological index in the village remained fairly high. At Odortom II, a significant reduction in miracidial transmission was obtained after SPC 1, but transmission increased after SPC 2. This occurred after the falling water level enabled offshore *Ceratophyllum* to invade the WCS and to maintain a submerged, semi-barrier around it, keeping the water calm and helping to concentrate miracidia closer to the sentinel snails.

DISCUSSION

The changes in the lake water level greatly affected the miracidial detection programme. Each year, sentinel snail infection rates were highest in the season of early lake drawdown and lowest at low water. At high water level, WCSs were smaller because of the

Table 4. Effects of the chemotherapy programme on sentinel snail infection rates in 16 villages

Village	Pre-intervention		Post-intervention			
			1976[a]		1977[b]	
	No. positive/ No. tested	%	No. positive/ No. tested	%	No. positive/ No. tested	%
Pawmpawmnya No. 1	12/2697	0.45	0/934	0	0/569	0
Fatem	97/2858	3.39	3/919	0.33[c]	5/812	0.62[c]
Kasa	95/2833	3.35	68/938	7.25[c]	101/812	12.44[c]
Poakwe Pawmpawmnya	33/2898	1.14	9/943	0.95	1/824	0.12[c]
Dawa Kofi	69/1831	3.77	24/854	2.81	6/632	0.95[c]
Akokoma	31/1619	1.91	10/885	1.13	4/676	0.59[c]
Kwabia	69/2735	2.52	2/883	0.23[c]	1/558	0.18[c]
Kuma Kuma	103/2878	3.58	4/868	0.46[c]	3/826	0.36[c]
Akrusu	82/1049	7.82	33/751	4.39[c]	20/716	2.79[c]
Asakeso	57/2791	2.04	28/785	3.57[c]	25/705	3.55[c]
Akotui West	134/2949	4.54	20/977	2.05[c]	5/585	0.85[c]
Akotui East	41/1193	3.44	0/691	0[c]	0/577	0[c]
Tamayeso	118/1799	6.56	17/791	2.15[c]	9/662	1.36[c]
Nyafutu	43/1664	2.58	10/658	1.52	13/660	1.97
Dukuase	139/1714	8.11	28/734	3.81[c]	21/672	3.13[c]
Odortom II	163/2069	7.88	6/654	0.92[c]	44/628	7.01

[a] After one round of chemotherapy.
[b] After two rounds of chemotherapy.
[c] Significant difference pre- and post-intervention, $P<0.05$.

wide zone of marginal emergent vegetation, and the majority of the sites were pocket-shaped. The side vegetation and the shore itself created barriers which concentrated the miracidia inside the WCS while keeping the water calm. Such well-defined sites made it very easy to pinpoint the centre of human water-contact activity. In this condition, both miracidial and cercarial transmission were focal and consistent (*11*). Channel-shaped WCSs were also common at high water levels, but because human activity was confined to narrow spaces near the shore, the sentinel snail cages in the water were often disturbed. The increased pollution near the shore also increased sentinel snail mortality and reduced miracidial infection rates. Almost all WCSs were of the open beach type at low water level each year. With no emergent vegetation in the water to confine human activity, water contact was more diffuse and miracidial density was considerably reduced. Sentinel snail infection rates in these WCSs were always very low except when moderate to heavy growths of *Ceratophyllum* were present.

While it is often difficult to pinpoint human water-contact sites in other schistosome habitats such as irrigation canals, ponds, and swamps, the WCSs in the Volta Lake were usually very distinct and consistent. Intensity of water contact was high, not only because the villagers were mainly fisherfolk, but also because the lake water was of good quality and therefore attractive as a water source. Also, during the hot season, children often used the open beach WCSs for swimming and playing. With such intensive water contact in all villages, a correlation between sentinel snail infection rates and the epidemiological index of the disease in the villages would be expected.

In the St Lucia schistosomiasis control project miracidial detection using sentinel snail exposure was used to help evaluate the efficacy of chemotherapy (*12, 13*), and no infected snails were found after chemotherapy had been started. In the present project, infection rates of sentinel and field snails were found to be proportional to the epidemiological indices of schistosomiasis in the villages in the pre-intervention period. However, the results after intervention were quite different. Sentinel snails were uninfected in only 2 of 16 villages studied. In 9 of the remaining 14 villages, the reduction in sentinel snail infection rates was proportional to the reduction in epidemiological levels of the disease. In the remaining 5 villages, however, there was no such relationship because of the ecological conditions of the WCSs changed thus favouring transmission.

Control of schistosomiasis in this area is difficult because of: (1) the poor cure rate of metrifonate in a high endemic area, (2) the high level of migration of the population looking for more productive fishing and farming grounds, (3) the large number of untreated people living in hinterland villages, 1–5 km from the lake, and (4) the large proportion of untreated people living in the villages undergoing intervention. Even where the project reduced epidemiological indices and sentinel snail infection rates by 90%, the residual disease could lead to a build-up of cercarial transmission within 2–3 months if snails were present during the main transmission season.

From this study, it can be concluded that chemotherapy, mollusciciding, and limited well-water supply are not sufficient to stop transmission of *S. haematobium*, although they achieved excellent results in the short-term control of transmission and infection. Permanent control would require the virtual eradication of infection from the project area, the nearby hinterland villages, and a wide zone along the lake on each side of the project area.

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RÉSUMÉ

DYNAMIQUE DE LA TRANSMISSION DES MIRACIDIES DE *SCHISTOSOMA HAEMATOBIUM* DANS LE LAC VOLTA

Pendant cinq ans, on a effectué des études sur la dynamique de la transmission des miracidies de *Schistosoma haematobium* tous les mois dans seize villages lacustres en plaçant des mollusques sentinelles dans des lieux de contact homme-eau.

On s'est aperçu que les taux d'infection des mollusques sentinelles avaient un caractère saisonnier, qu'ils étaient élevés lorsque le niveau de l'eau était haut et peu élevés lorsque le niveau de l'eau était bas. On a découvert que les mollusques étaient plus souvent infectés dans les petites poches d'eau que dans les plages ou canaux largement ouverts. Les maximums dans les taux d'infection des mollusques sentinelles étaient comparables à ceux des mollusques vivant à l'état naturel et correspondaient aux niveaux épidémiologiques de la schistosomiase parmi les habitants locaux.

Après deux ans d'intervention par chimiothérapie et l'emploi de molluscides, les taux d'infection des mollusques sentinelles n'avaient diminué que dans deux tiers des villages. Dans les autres, le changement dans le taux d'infection des mollusques sentinelles ne correspondant pas à la baisse des niveaux épidémiologiques, en raison de modifications écologiques dans les lieux de contact avec l'eau. Certaines modifications de ces lieux de contact entraîneront rapidement une reprise du taux de transmission de la maladie même après une baisse de 90% des niveaux épidémiologiques.

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Ecological studies of *Bulinus rohlfsi*, the intermediate host of *Schistosoma haematobium* in the Volta Lake

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In the present ecological study of cercarial transmission of Schistosoma haematobium *in the Volta Lake, Ghana, habitat observations and sampling of* Bulinus truncatus rohlfsi *were conducted within a 60-km stretch of shoreline. Observations revealed that human water contact sites in each village undergo constant changes in shape and vegetation. Snail sampling surveys in water contact sites were carried out monthly (for 27 months) in 8 villages using newly designed palm-leaf traps, and in 8 additional villages (for 16 months) using a modification of Olivier & Sneidermann's man–time method. Results to date confirm the finding by Chu & Vanderburg that cercarial transmission in the lake takes place almost exclusively within water contact sites. Additional results indicate that even within individual water contact sites this transmission is focal, most infected snails being found very close to the shoreline. Transmission also varies significantly according to shape, vegetation, and geographical location of the water contact sites, and is distinctly seasonal in most villages. These findings lead us to conclude that control of cercarial transmission in the Volta Lake is both attainable and feasible with existing methods.*

The formation of the man-made Volta Lake in Ghana in 1964 created an ideal environment for the snail vector of urinary schistosomiasis, resulting in an explosion of disease transmission in most communities surveyed (*9*).[a] Combined with reports of increased prevalence rates of schistosomiasis in other man-made lakes in endemic areas, this underlined the need for thorough research into the ecology of schistosomiasis in these environments to determine whether control of disease transmission is feasible.

Such research is being conducted in a WHO/UNDP schistosomiasis project along a 60 kilometre stretch of the Volta Lake shoreline. Results of the project's pre-intervention baseline surveys on the ecology of cercarial transmission within human water contact sites are presented in this report. In particular, the report describes ecological characteristics of the water contact sites, vector snail densities, vector snail population fluctuations, and patterns of cercarial transmission.

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[a] Jones, C. R. *Health component in the Volta Lake research project. Report on project results, conclusions and recommendations.* WHO unpublished document AFR/PHA/115; AFR/SCHIST/27 (1973).

Most of the early malacological and epidemiological work on the disease in the Volta Lake was conducted by Paperna (*9, 10*). He found the first living *Bulinus truncatus rohlfsi* (called *B. rohlfsi* in this paper) in the lake in August 1966 and soon afterwards reported the subsequent rapid proliferation and spread of the species in association with floating masses of vegetation and new growths of *Ceratophyllum*. By January 1967, he found that transmission of urinary schistosomiasis in some sectors of the lake was already widespread. Paperna later confirmed that the parasite was *Schistosoma haematobium* and that it was highly compatible with *B. rohlfsi* from pre-existing lakes to the north of the dam and from the Volta Lake. Further field studies by Odei[b] established that *B. rohlfsi* was the most common lake snail and the only existing snail vector of human schistosomiasis in the lake.

While working in a WHO-Ghana Government Volta Lake project, Jones[a] reported increasing human prevalence rates throughout 1971 in all lakeside settlements originally sampled independently by Paperna and Senker (unpublished reports). This

[b] Odei, M. A., cited in Jones, C. R., *op. cit.*

contradicted earlier speculation by Watson [a] that transmission of the disease in the lake was stabilizing. Recently, Chu & Vanderburg (2) confirmed Paperna's finding (unpublished report) that cercarial transmission occurred only in populated areas and they showed that this transmission was confined almost entirely to human water contact sites.

[a] Watson, J. M. Assignment Report, Volta Lake Research Project, Health Component. Ghana 0041. Unpublished document WHO/AFRO (1970).

PROJECT AREA

Location and demography

Fig. 1 shows the project area in relation to the entire lake together with an enlarged map of the

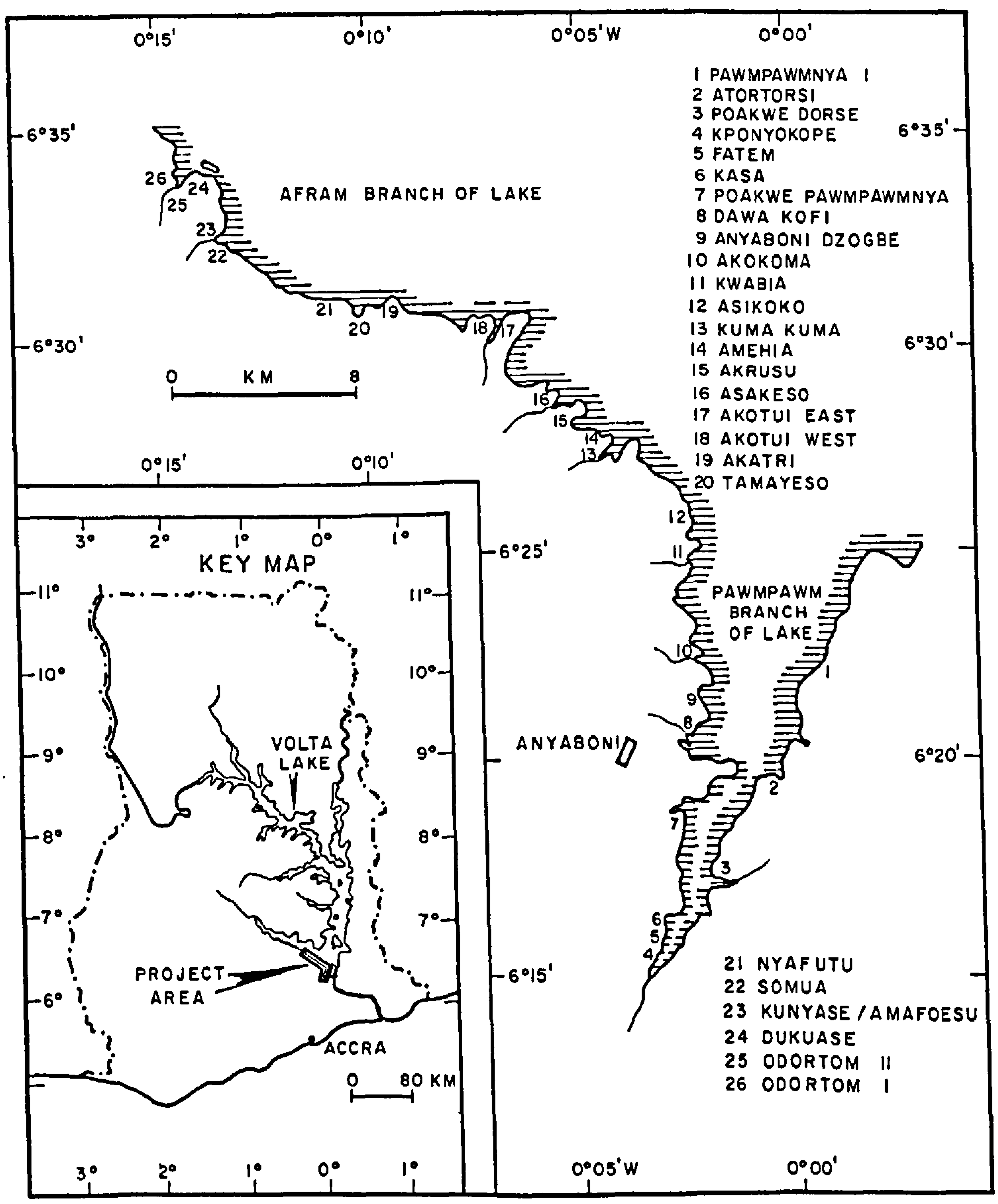

Fig. 1. Project area showing 26 study unit villages.

project area indicating the location of all 26 study unit villages. These settlements are scattered within 60 nautical km of undulating shoreline that is accentuated by many small, narrow inlets and coves. Three study unit villages are located within a 10-km section on the eastern shore of the small Pawmpawm branch. The remaining 23 are situated along 50 km of the western shore, from the southern end of the Pawmpawm branch to the south-eastern section of the large Afram branch. The project field station is located at the Anyaboni resettlement town, 45 km by road from Koforidua to the south-west and 130 km from Accra to the south.

About 4300 people reside in the 26 villages. Most of these villagers are Ewe fishermen and their families who emigrated to the lake from areas in the Volta River delta. The indigenous land owners in the area are the Krobos, traditionally farming people. Prevalence rates of *S. haematobium* among all age groups in the 26 villages ranged from 31.7 to 100%, most villages having prevalence rates greater than 80%.

Vegetation and climate

The project area lies at the boundary of the moist semi-deciduous forest zone (to the west) and the drier Guinea woodland zone (to the north and east). Except for the deepest parts, much of the lake is full of projecting dead hardwood trees and submerged tree stumps. In some sections, forests of these dead trees serve as effective wave brakes around water contact sites and allow for massive growths of the submerged weed, *Ceratophyllum*.

Annual rainfall normally ranges from 1000 to 1400 mm. The rainy season extends from March to early November with precipitation maxima usually in June and September. Rainfall is infrequent between mid-November and early March.

Modal air temperatures range from 29°C to 33°C (daily maxima) and from 20°C to 24°C (daily minima). Temperatures are coolest during the months of maximum rainfall and usually highest in February, March, and April. The greatest daily maximum-minimum temperature fluctuation usually occurs in January (" harmattan " period).

Villages selected for biological study

Eight study unit villages were originally selected for intensive biological study based on criteria outlined in the original project design. The villages include Pawmpawmnya I (study unit 1), Fatem (study unit 5), Kasa (study unit 6), Poakwe Pawmpawmnya (study unit 7), Kwabia (study unit 11), Kuma Kuma (study unit 13), Asakeso (study unit 16), and Akotui West (study unit 18). In these villages, monthly pre-intervention (baseline data) snail sampling surveys in water contact sites, along with associated ecological observations, began in March 1973 and continued until the end of May 1975. Snail sampling was conducted with standardized traps made of woven palm-leaf mats.

Soon after baseline surveys began, it was found that the first 8 villages inadequately represented the full range of ecological conditions within the project area, especially in the north-western sector where human prevalence rates were consistently higher. A second group of 8 villages was therefore selected in January 1974 to enlarge the monthly snail sampling programme. These villages included Atortorsi (study unit 2), Dawa Kofi (study unit 8), Akokoma (study unit 10), Asikoko (study unit 12), Tamayeso (study unit 20), Nyafutu (study unit 21), Dukuase (study unit 24), and Odortom II (study unit 25). In these villages, snail sampling was conducted using a modification of Olivier & Sneidermann's man–time method (*8*).

Molluscs found in the lake

The following molluscs were collected from project snail sampling surveys.

(1) *Bulinus rohlfsi* — the most abundant snail and the only species found infected with a human schistosome species;

(2) *Bulinus forskalii* — the second most abundant snail;

(3) *Lymnaea natalensis* — sporadically found in light density in or near stream inlets with heavy emergent and floating vegetation;

(4) *Lanistes varicus* — found occasionally in the Pawmpawm branch;

(5) *Ferrissia eburnensis* — found occasionally; mainly in high water periods;

(6) *Physa waterloti* — found in streams inlets, mainly during high water periods;

(7) *Gyraulus costulatus* — found mainly during low water periods;

(8) *Anisus coretus* — rarely found;

(9) *Calelatura* sp. and *Mutela* sp. — bivalves found infrequently in sandy water contact sites.

ECOLOGICAL OBSERVATIONS

Water quality measurements

Selected physical and chemical parameters were measured monthly in the main water contact sites of each of the first 8 villages to determine aspects of water quality. The parameters were: water temperature, pH, turbidity, total alkalinity, hardness (calcium and total), and total iron. From March 1973 until the end of June 1974 water temperatures were taken at midday; subsequently, they were measured between 08 h 00 and 10 h 00. All temperatures were taken just below the surface of the water near the shore at 3 locations per site. The values of the other variables were obtained by means of the Hach Kit with sample collections also taken near the shore and laboratory analyses made the same day.

The monthly mean midday water temperatures ranged from 27.3°C to 31.0°C while mid-morning values were between 25.4°C and 28.8°C. Results of the other water quality measurements are summarized in Table 1. Little monthly variation occurred but monthly mean values of all parameters were slightly lower after the first full year of study.

Because of the few prior published studies and differences in time, location, parameters measured, and equipment, it is difficult to compare precisely the present results with physico-chemical data of others working in the Volta Lake; however, comparison of the same parameters shows that the present findings differ insignificantly from earlier mean values obtained in the lake (*3*, *4*, *5*).

Lake level fluctuation

The ever-changing lake level was monitored regularly from official Volta River Authority measurements taken at the Akosombo Dam. To study the horizontal movement of shorelines in the project area, a permanent marker (either a pole or a tree) was established during the high water period of 1972 at each main water contact site in the first 8 villages. Respective distances from these markers to the changing shoreline were then measured during each monthly snail sampling survey.

Table 1. Results of physico-chemical analysis of water from the main water contact sites in the first 8 villages

Parameter	Mean	Range
Alkalinity (mg/l)	44.6	30–60
pH	7.2	6.3–8.7
Hardness (calcium) (mg/l)	19.4	15–30
Hardness (total) (mg/l)	30.9	20–50
Total iron (mg/l)	0.08	0.01–0.55
Turbidity (FTU)	18.0	2–115

From the Volta River Authority data, annual fluctuations of the lake since final controlled impoundment in 1967 averaged 2.7 m, although the fluctuation was 4.3 m in 1974. Each year, the flood period of the lake began in late July or early August, water rise was most rapid in September and October, and from early November an 8½ to 9 month period of lake regression occurred at a steady rate.

From our data, individual horizontal shifts of water contact site shorelines across the drawdown area ranged from 19 to 148 m per month during periods of most rapid lake rise and from 0 to 51.5 m per month during periods of lake drawdown. Thus sampling areas in water contact sites never overlapped between consecutive monthly surveys during the former periods and only partially overlapped between consecutive surveys in the latter periods.

Vegetation

There are three distinct and consistent ecological phases related to the growth of drawdown zone vegetation and the concomitant shape of water contact sites during each annual cycle of lake fluctuation. We classified these phases as follows: (1) the rising water phase (August to October); (2) the early to mid-drawdown phase (November to March); and (3) the late drawdown phase (April to July). For convenience, the third phase will be described first.

Late drawdown phase. In this period, the water recedes beyond the limit of rooted, emergent vegetation in most locations, initially leaving bare shores. As the water retreats further, new plants begin to sprout across the muddy or sandy shores, enhanced by the increasing rains. At the end of the late drawdown phase, a distinct zone of young sedges, sprouting *Polygonum*, and creeping plants dominates this low zone. The most frequently observed sedges were *Cyperus distans* and *Scirpus cubensis*; the most common of the creeping plants were *Ludwigia stolonifera* and *Alternanthera sessilis*.

The plant mass in the water that does not change during this phase is *Ceratophyllum*. In some locations, especially in the north-western sector of the project area, massive belts of *Ceratophyllum*, many metres wide, grow from the lake bottom to the surface. Sometimes these belts stretch continuously for hundreds of metres parallel to shore, from shallow water to depths exceeding 5 m; however, when the receding water strands these masses in very shallow water, the plants wither and die. In many water contact sites, *Ceratophyllum* fragments are commonly washed in from deep-water belts. Fragments are also carried into water contact sites in fishermen's nets.

Rising water phase. Beginning in each August, the rising water rapidly inundates the plants growing in the low-shore zone and thus strands the *Ceratophyllum* masses in deep water. Unless they form floating " sudds ", like *Scirpus–Ludwigia* mixtures, the sedges and creepers soon die under the water. The flooding then advances quickly through the zone of tall emergent plants that occupy a wide foreshore zone between high and low water levels. Most of these plants grow rapidly when flooded and continue to maintain their foliage above water. The most common species observed in this zone were *Polygonum senagalense*, *Paspalum orbiculare*, *Echinocloa stagnina*, and *Sorghum arundinaceum*.

As the lake reaches its annual peak, plants in the highest foreshore zone become flooded for about 3–6 weeks depending on the slope of the land. Because the area is cultivated for drawdown farming, many water contact sites in this high zone contain less natural vegetation.

Early to mid-drawdown phase. During this phase, the water retreats back into the mid-zone of the emergent grasses or *Polygonum* that survive flooding very well. Where the slope is very gradual, wide zones of solid *Polygonum* and *Paspalum* are sometimes encountered, sometimes partially or completely surrounding water contact sites for many months.

Ceratophyllum growth in the deep water of inlets and coves flourishes during this period of high water. Although masses of the plant remain offshore, the fragments that wash into water contact sites often begin growing again in the shallow water.

Ecological types of water contact site

Human water contact sites are located at the ends of footpaths leading from family compounds to the lakeshore in every lakeside village. These footpaths rarely change in direction and most human water contact such as bathing, fetching water, washing, etc., is confined to the shallow water at points where the footpaths enter the lake. But because of lake rise and fall, all water contact sites shift constantly back and forth across the foreshore, following the line of the footpaths and thus frequently changing in shape and ecology. To date, 11 different ecological types of water contact site have been observed. We classified these according to shape, vegetation density, and location in the foreshore as follows:

Type 1 = open beach with no visible vegetation
Type 2 = open beach with light to moderate vegetation
Type 3 = open beach with heavy vegetation
Type 4 = pocket-shaped with no visible vegetation
Type 5 = pocket-shaped with light to moderate vegetation
Type 6 = pocket-shaped with heavy vegetation
Type 7 = short channel through emergent vegetation (less than 30 m long from shore to open water)
Type 8 = long channel through emergent vegetation (30 m or longer)
Type 9 = open beach at still stream with no visible vegetation
Type 10 = open beach at still stream with light to moderate vegetation
Type 11 = open area within emergent vegetation with narrow offshore outlet channel.

Because some of the 11 types are encountered infrequently, they can be grouped into 3 main categories of water contact sites based on shape: (1) open beaches (types 1, 2, 3, 9, and 10); (2) pockets (types 4, 5, and 6); and (3) channels (types 7, 8, and 11). At most villages, all water contact sites exist in some form of open beach, pocket, and channel type during each lake cycle. The observed monthly frequencies of these 3 water contact site groupings are shown in Fig. 2 for the first 8 villages combined. It can be seen that each year, almost all water contact sites were open beaches from April to August; most water contact sites were pocket-shaped from December to February or March; channel-shaped water contact sites were most numerous each year from September or October to November or December.

Surface area measurements were made each month for all main water contact sites in the first 8 villages. When these sites were grouped into the 3 categories of shape, their total average surface areas were as follows: open beaches, 637 m^2; pockets, 433 m^2; and channels, 288 m^2. Areas for open beach sites were the most difficult to measure because of non-existent side vegetation boundaries. For these sites, area calculations had to be based on measurements of assumed maximum water contact activity. Measurements for pockets were less arbitrary; and measurements for channels were the most precise.

Since each individual type of water contact site has evolved according to lake level and vegetation growth, the creation of each type should be discussed in relation to the three ecological phases of each lake cycle.

Late drawdown phase. After the water recedes beyond the emergent vegetation, water contact sites turn into open beaches with sandy or muddy shorelines. The vegetation in these water contact sites is therefore almost entirely submerged *Ceratophyllum*. Along narrow stream inlets, extremely low water levels sometimes cause the lake water to recede within the original stream channels. When this occurs, water contact sites of types 9 and 10 are created.

Rising water phase. The initial flooding first shifts water contact sites back up the foreshore so that the water soon reaches the taller perennial grass or *Polygonum* still surviving on the sides of the footpaths. At this time, most water contact sites are initially pocket-shaped but where the slope is gradual, continued flooding then shifts the water contact sites further up the inundated footpaths. This results in water contact sites becoming narrow water channels through the side vegetation boundaries from shore to the open deep water. In both long and short channel-shaped water contact sites, the emergent vegetation is usually high and dense enough to restrict human wading and canoeing to within the width of these passageways (normally less than 5 m). In some locations of least slope, long channel-shaped water contact sites measure over 150 m from shore to open water. When water reaches the highest foreshore zone, cultivated crops are harvested, creating open areas for water contact. Where narrow outlet channels remain behind these open areas, " type 11 " sites are created.

Early to mid-drawdown phase. While water is still high, most water contact sites remain in the shape of type 11 sites, or long channels. But soon after lake drawdown begins, the inshore emergent vegetation is stranded on land and the deepest offshore emergent vegetation begins to collapse and decay; thus, zones of healthy *Polygonum* or grasses left in the water shrink. When this happens, many water contact sites initially become short channels. As the water recedes further, water contact sites shift nearer to the offshore vegetation growth limit, widen, and become pocket-shaped. By April, water recession shifts most shorelines beyond the emergent plant limit and open beach sites are once more created.

FIELD OBSERVATIONS ON THE ECOLOGY OF *BULINUS ROHLFSI* IN WATER CONTACT SITES

Materials and methods

Standardized palm leaf mats, designed, developed, and tested by Chu & Vanderburg (*2*) were used for monthly snail collecting in the first 8 villages. In all water contact sites, mats were concentrated in shallow water, where most human activity took place. In addition, in each main (most heavily used) site, mats were also placed in deeper water (to a depth of 3 m) to ascertain the vertical and horizontal limits of potential deep water cercarial transmission. Depend-

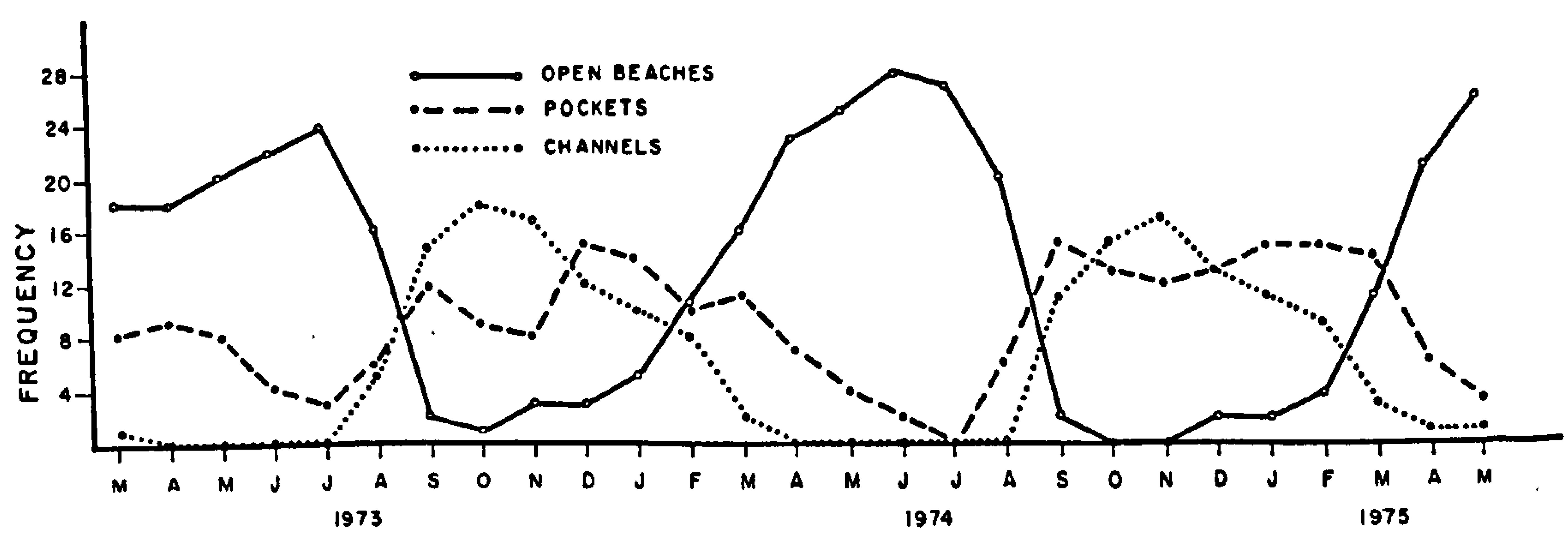

Fig. 2. Monthly frequency of open beach, pocket, and channel groupings of water contact sites.

ing on local conditions, 3 different positions of mat placement were used: (1) anchored on the bottom, (2) placed at the water surface in floating vegetation, and (3) set directly on top of *Ceratophyllum*, at varying depths, with or without stone anchors.

The same number of mats was used each month within each water contact site. In the 8 main water contact sites, this number ranged from 30 to 43; for the lesser-used water contact sites, from 5 to 15. Because water contact sites change in shape and size every month, the arrangement of the mats within each site was subject to variation; however, a similar arrangement of mats at each water contact site was maintained as far as possible.

After placement, the palm mats were left in the water for two days. They were then carefully retrieved individually and immediately examined for snails. If found, *B. rohlfsi* specimens of 3 mm shell height or greater were placed in collecting bottles and labelled according to location within the site. Smaller specimens were returned to the water. Collected snails were examined within a few hours at the Anyaboni field laboratory. All snails were individually measured, crushed, and examined under a dissection microscope for evidence of trematode infection. When *S. haematobium* cercariae were detected, the total number in each crushed snail was counted, usually by the same examiner. These infected snails were carefully teased apart and counts were made of mature, active cercariae.

However, among cercarial infections just maturing, some immature cercariae with forked tails were probably counted. This may have led to a slight overcounting in these snails.

Modified man-time sampling

Modified man-time sampling was begun in February 1974 in each of the 2 most heavily used water contact sites of the second 8 villages. Because of the ecological changes in the drawdown areas during the course of each lake cycle, it would have been possible to follow Olivier & Sneidermann's man-time sampling method (*8*) only at low water periods when the sites were more open and consistent in shape. During the rising and high water periods, the rapid shifts in shorelines and the long narrow nature of water contact sites precluded any attempt to apply the low water sampling routine. In these high water sites, some sampling had to be conducted with chest waders, or from canoes in deeper water, and this made manoeuvering more difficult. Also, the rooted emergent vegetation posed additional sampling problems. During the rising water phase, snail density was not only lower but occasionally snails were found only on the tangled stems or in the buried roots of *Polygonum*.

As practiced here, four men, each equipped with waders, dip-nets, rubber gloves forceps, and collecting bottles, hand-searched for snails in the water for 15 minutes (one man-hour of sampling). Two men were stationed in individual areas near shore and two men in individual areas in deeper water. At wide open sites, all four men used waders, but in channel-shaped sites, one or two men often used canoes and sampled by pulling up and examining vegetation on each side of the water contact site. When snails were found, they were recorded and examined in the same way as snails obtained by palm-mat sampling.

RESULTS

Snail-vegetation association

In both sets of 8 villages sampled, *Ceratophyllum* was by far the most important plant in promoting largest numbers of the vector snail (Table 2). By palm-mat sampling, 68.5% of all *B. rohlfsi* were associated with *Ceratophyllum*, and by modified man-time sampling, 83.5% of the snails collected were picked directly from the plant. The higher figure by the latter sampling method was due to

Table 2. Percentage frequency of all snails collected in relation to vegetation

Vegetation	Palm-mat sampling [a] (%)	Modified man–time sampling [b] (%)
Ceratophyllum	68.5	83.5
Polygonum	11.4	8.8
None	8.4	0
Paspalum	6.4	0.7
Pistia	2.8	0.1
Ludwigia	0.3	1.6
Alternanthera	1.4	0
Palm branches	0	2.1
Other	0.8	3.2

[a] From associated main vegetation under or immediately adjacent to mats.
[b] From which snails were directly collected.

higher densities of *Ceratophyllum* in the second 8 villages, together with the tendency of the snail collectors to search out this plant in sites of mixed vegetation. Total percentage catches from *Polygonum* amounted to 11.4% by palm-mat sampling and 8.8% by modified man–time sampling. The other plants were of much less significance. After 1974, *Paspalum* spread rapidly throughout most of the first 8 villages but never promoted large snail densities. *Pistia*, *Ludwigia*, and *Alternanthera* were common throughout the project area but were also not favoured by *B. rohlfsi*. Fallen palm branches were only occasionally found in water contact sites. By modified man–time sampling, 2.1% of all snails were collected from such palm branches.

In palm-mat sampling, 8.4% of all snails collected came from areas with no visible vegetation. In most cases, scattered clumps of vegetation were nearby in other sub-sampling areas but occasionally snails in low density were attracted out of mud on to mats in sheltered sites completely devoid of vegetation. These snails were exceptionally large and showed very high rates of infection by *S. haematobium*. In modified man–time sampling, snails were never found in water contact sites devoid of vegetation even though, at such sites, dip-nets were pushed back and forth along the bottom of the total sampling areas.

Horizontal density

Chu & Klumpp (*1*) studied the horizontal density of *B. rohlfsi* over a two-year period in the main water contact site at Akotui West by placing standardized rows of palm mats at fixed distances from shore each month. This was possible because the water contact site maintained the same basic shape throughout most of the year. The highest average density of all snails collected (19 snails per 10 mats) occurred at an average distance of 10 m from shore where *Ceratophyllum* density was usually greatest. (Snail density dropped off sharply beyond an average distance of 13 m from shore and was very low at 19 m). Of snails with mature *S. haematobium* infections, highest average density (2.7 infected snails per 10 mats) occurred within 2 m from shore. At 4, 7, and 10 m from the shore, this density dropped by approximately 45%, respectively; it dropped further by almost 85% between 13 and 16 m, and was only 0.1 infected snail per 10 mats at 19 m from shore.

Findings from the second 8 villages confirmed that most snails infected with *S. haematobium* occur very close to shore. In every water contact site sampled, 2 inshore areas were normally sampled within 10 m from shore and 2 outer areas were normally sampled between 10 and 20 m from shore. Totalling snail catches from all villages, 1002 snails with 90 mature infections were collected from inshore areas and only 590 snails with 32 mature infections were collected from outer areas.

Snail catches by ecological type of water contact site

Table 3 lists the number of snails with mature *S. haematobium* infection, the number of snails collected, mean cercarial counts of infected snails, and mean shell heights of the infected snails in the 11 different ecological types of water contact sites encountered in all 16 villages. This table also indicates the order of importance of the types of habitat for potential cercarial transmission. The ranking order was based on the number of mature snail infections of each ecological type per number of times sampled. By far the largest numbers and highest densities of infected snails came from pocket-shaped sites containing vegetation.

Very few snails were collected from open beach sites without vegetation (types 1 and 9) even though these latter sites were encountered almost as frequently as the above pockets. The fourth highest density of infected snails came, however, from open beach sites with light to moderate vegetation. This vegetation was almost exclusively *Ceratophyllum*, which kept the water fairly still and thus enhanced schistosome transmission. Snail densities were very low in long channel sites, especially near shore, but short channel and type 11 sites, usually evolving from shrinking long channels, contained fairly high densities of infected snails.

Table 3 also shows the differences of mean cercarial counts in crushed infected snails from the five habitats yielding most snails with mature infections. Mean counts were lowest in snails from type 2 (open beach) sites and highest in snails from short channel sites. These differences are due to corresponding differences in mean sizes of the infected snails: the larger the snails, the more cercariae and *vice versa* (see Fig. 6). Similarly, the ecological conditions in each type of habitat determine mean snail size. Infected snails were largest from short channel and type 11 sites because the water there is calmest, vegetation most abundant, and bottom substrate richest in mud and organic matter. Infected snails were smallest from the open beach sites because there was more wave action, shores were more sandy, and less organic matter existed.

Table 3. Number of mature *S. haematobium* snail infections, *Bulinus rohlfsi* collected, mean cercarial counts, and mean infected snail sizes in different ecological types of water contact sites sampled

Type	Shape of water contact site	Vegetation	No. of times sampled	No. of mature snail infections	No. of snails	Mean no. of cer./inf. snail	Mean shell height/inf. snail (mm)
5	pocket	light–moderate	204	276	3138	104.2	5.74
6	pocket	heavy	92	81	1595	107.7	5.87
7	short channel	heavy	45	27	294	134.9	6.35
2	open beach	light–moderate	186	88	1035	85.9	5.23
11	opened area with channel outlet	light-moderate	118	38	547	119.9	6.15
3	open beach	heavy	12	4	116		
4	pocket	none	8	2	26		
10	open beach at still stream	light–moderate	29	2	65		
8	long channel	heavy	78	3	119		
1	open beach	none	218	1	45		
9	open beach at still stream	none	24	0	1		

Monthly snail population fluctuations and rates of infection

Total monthly rates of mature *S. haematobium* infection in *B. rohlfsi*, combining all sampled water contact sites in the first and second 8 villages are shown with monthly lake levels in Fig. 3 and 4, respectively. In both groups of villages, percentages of infected snails were relatively high and generally not dependent on snail density. The total overall infection rate in the first 8 villages was 7.4% and in the second 8 villages, 7.7%. These rates of mature infection agree closely with rates obtained in earlier field work by Odei [a] in the Afram branch of the lake. Of the 1325 *B. rohlfsi* he collected between 1970 and 1972, 7.6% shed cercariae presumed to be *S. haematobium.*

Fig. 3 shows several seasonal trends. Snail catches and numbers of infected snails were unusually high from March to the end of July 1973, during the late drawdown phase of open beaches. This was due primarily to thick growths of *Ceratophyllum* at the villages of Poakwe Pawmpawmnya, and Akotui West which enabled large snail populations to develop in the littoral zone. The rising water phase then caused a sharp drop in overall snail density. Numbers of infected snails were thus extremely low in all villages during September and October. After the lake drawdown began in November 1973, snail populations expanded in almost every village and the numbers of infected snails were very high until the end of March 1974. After that, extreme water recession caused almost all water contact sites to be transformed into open beaches with either little or no *Ceratophyllum*, resulting in low snail densities. With snail populations at such a low ebb, the sharp rise of the lake in September prevented the build up of snail populations and corresponding snail infections until December. In January 1975, the explosion in snail numbers and infections occurred almost exclusively at the 3 sampled water contact sites of one village (Akotui West). In February, these 3 sites again accounted for most snails and infections. Although the water was still unusually high during March, April, and May 1975, numbers of snails and snail infections dropped off in a pattern similar to that of the same period of 1974 because of similar reduced growths of *Ceratophyllum.*

In the second 8 villages (Fig. 4), the monthly trends of numbers of snails and mature snail infections were broadly the same as in the first 8 villages;

[a] Odei, M. A. *op. cit.*

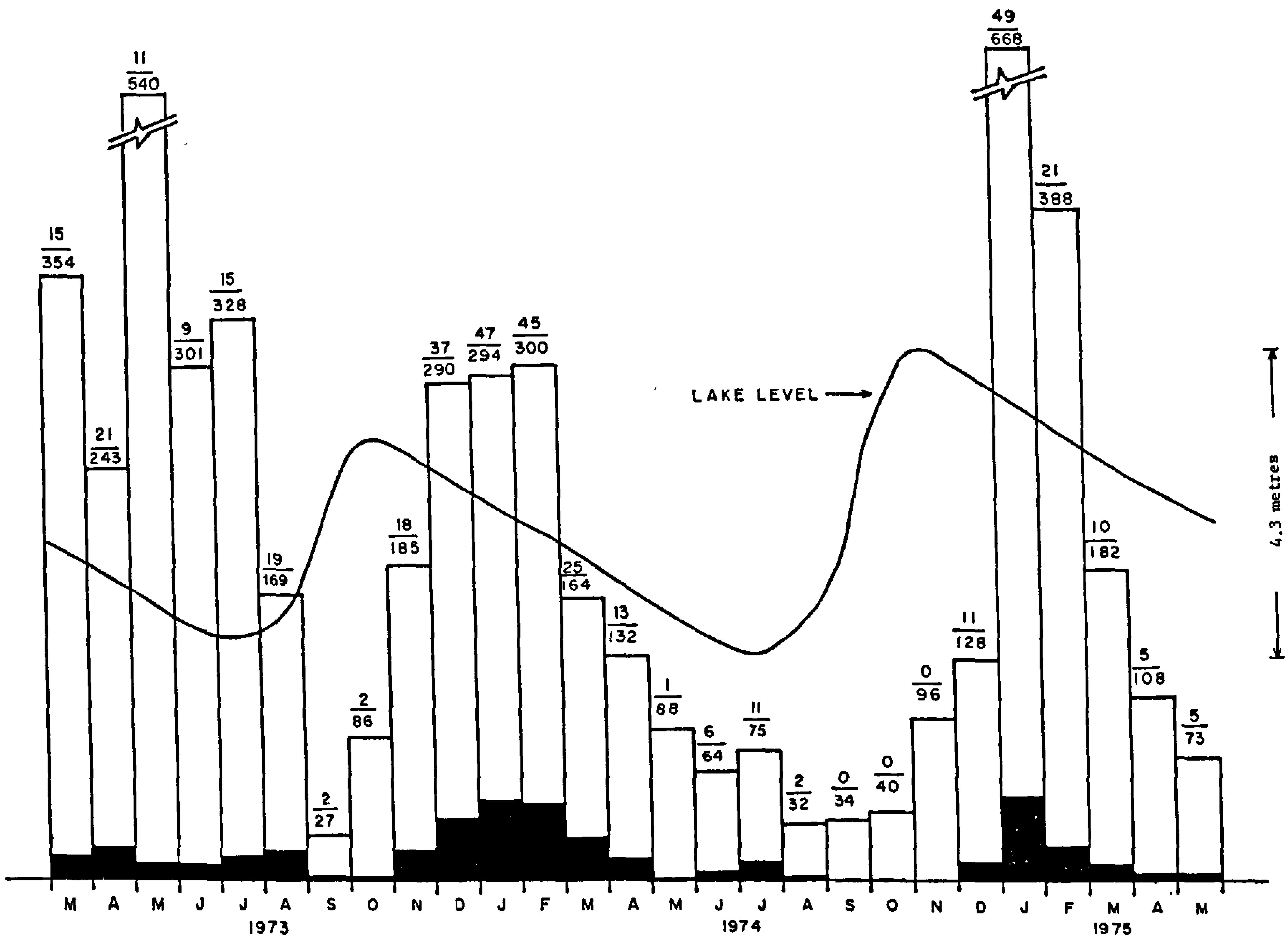

Fig. 3. Numbers of snails caught (open columns) and numbers of infected snails (black columns), by month, in relation to lake level: first eight villages.

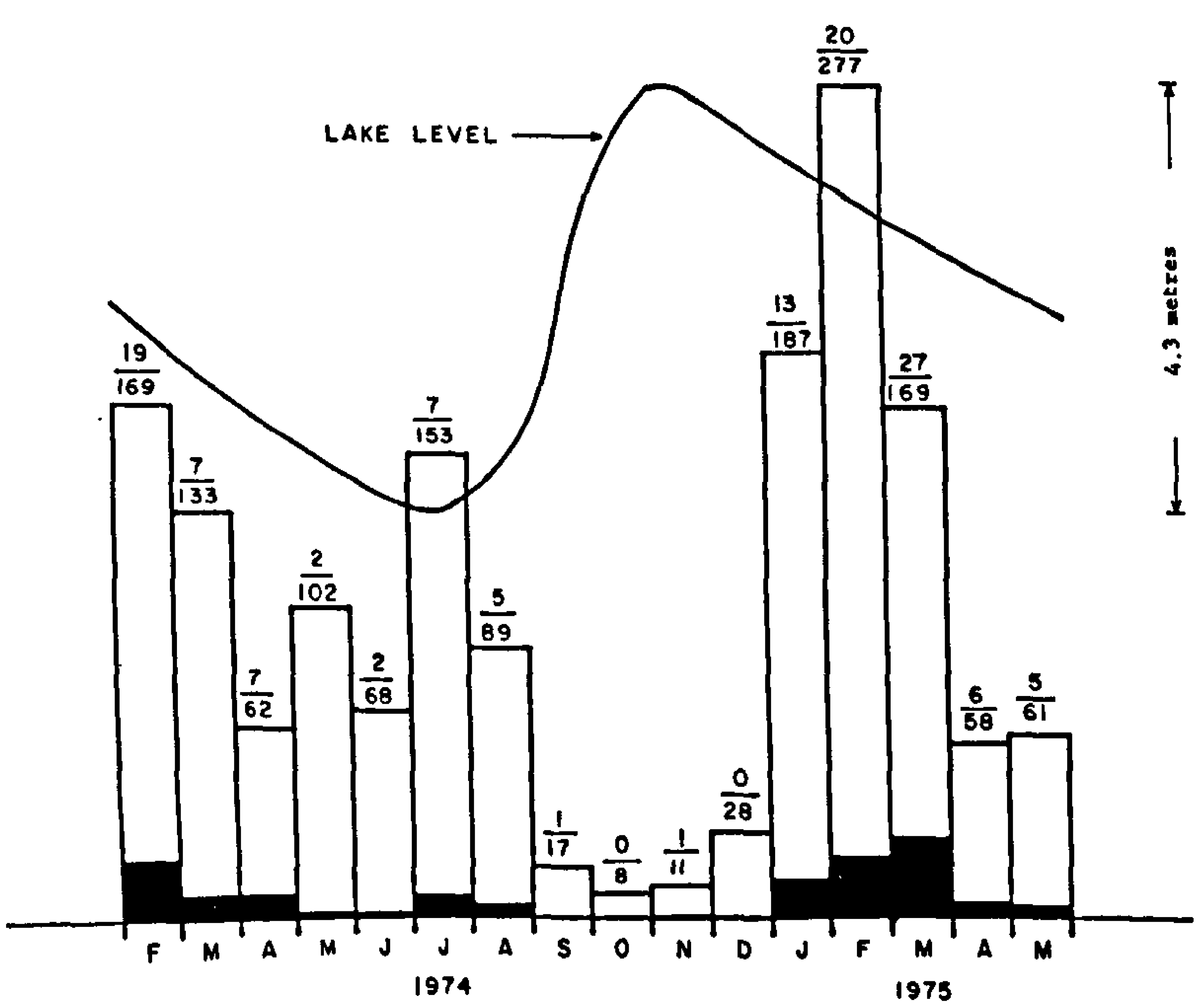

Fig. 4. Numbers of snails caught (open columns) and numbers of infected snails (black columns), by month, in relation to lake level: second eight villages.

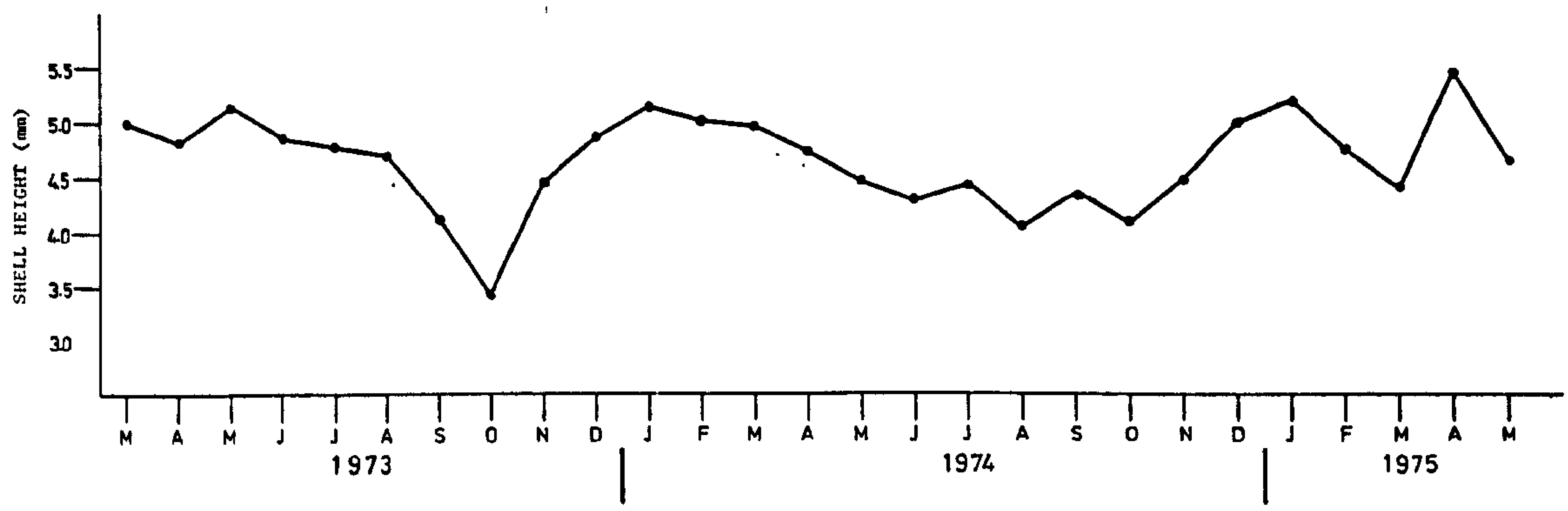

Fig. 5. Monthly mean snail shell height.

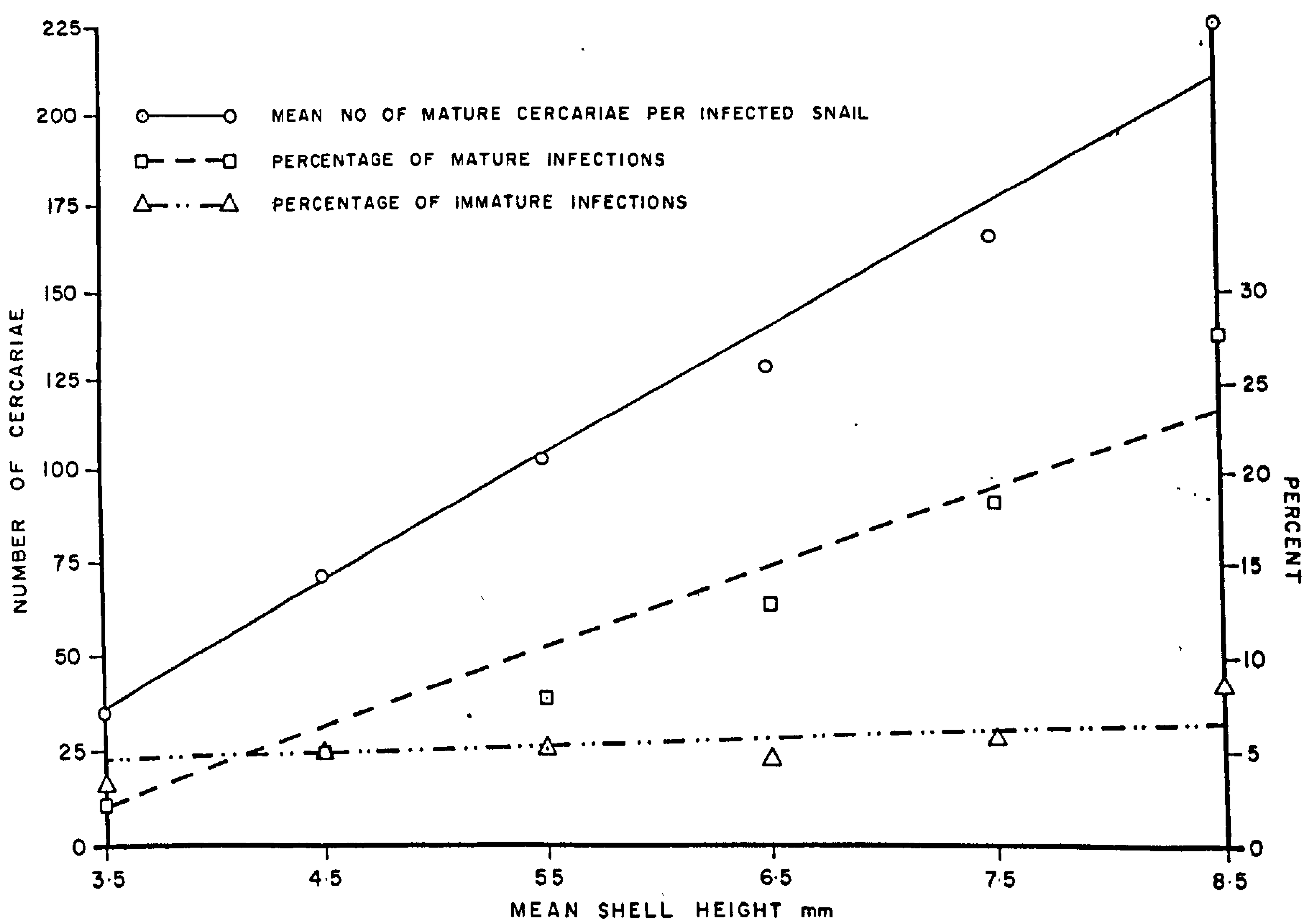

Fig. 6. Mean cercarial counts and percentages of *S. haematobium* infections in crushed *B. rohlfsi* according to shell height.

Table 4. Monthly number of mature *S. haematobium* infections in *B. rohlfsi* per number of all *B. rohlfsi* collected

Village	1973													
	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Pawm. I	0	0	0	0	0	0/3	0	0	0	0	0	0	0	0
Fatem	0/1	0	0	0	0	0	0/1	1/16	2/62	1/38	4/19	5/14	8/10	0
Kasa	0/22	3/18	0/19	1/17	0/48	2/12	0	0/14	2/19	1/23	6/59	1/18	1/5	0/9
P. Pawm.	7/190	5/71	8/363	0/89	0/142	1/40	0	0/4	0/4	0/12	0/34	0/32	1/33	1/64
Kwabia	0	0	0	0	0	0/4	0	0/2	0/5	1/4	1/8	0/7	0/6	0
K. Kuma	4/6	1/2	0	0	0	0/1	0	0/5	2/12	16/75	9/53	1/26	1/5	2/3
Asakeso	1/26	1/20	0/11	0/18	0/3	0/4	0/7	0/12	3/22	4/18	5/41	3/76	6/50	3/41
Akotui West	3/109	11/132	3/147	8/177	15/135	16/105	2/19	1/33	9/61	14/120	22/80	35/127	8/55	7/15

however, because of the exceptional flooding of late 1974, mature snail infections in 1975 did not begin until January, and did not reach a maximum until March.

Monthly mean shell height of all snails collected by palm-mat sampling is shown in Fig. 5. These data were more indicative of true snail size because modified man–time sampling showed an expected bias towards collection of larger snails. It can be seen that snail size was smallest during each rising water period. Snail size increased as habitats stabilized, the largest snails mostly being collected in January. Except for April and May 1975, average snail size during late drawdown periods gradually declined in a fairly steady manner.

Overall percentages of mature *S. haematobium* infections along with mean cercarial counts in all crushed snails (snails 3 mm and higher) increased in a linear progression with increasing snail size (Fig. 6). Percentages of immature cercarial infections detected, by contrast, were fairly constant regardless of snail size. These latter infections represented immature cercariae in the so-called "ball" or "dumb-bell" configuration, a stage lasting only about 7 days *in situ*. With our field crushing technique, we could not detect earlier stages of infection. We thus missed detecting about 75% of the total immature infections; these missed infections were probably more numerous in the larger snails.

Overall monthly rates of mature infections in

Table 5. Monthly number of mature *S. haematobium* infections in *B. rohlfsi* per number of all *B. rohlfsi* collected in second 8 villages

Village	1974											1975					Total	%
	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M		
Atortorsi	0/6	0	0	0	0	0	0	0	NS	0	0	0	NS	0/3	0	0/1	0/10	0
Dawa Kofi	4/27	2/24	0/8	0/14	0/5	0/7	0/3	0/6	0	0/1	0/3	5/15	0/14	7/14	1/4	1/2	20/147	13.6
Akokoma	0/17	0/10	0	0/3	0	0	0/3	0/1	0/1	0/3	0	0/18	1/33	7/32	0/15	0/6	8/142	5.6
Asikoko	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamayeso	0/4	0/3	0	1/21	0/4	0/4	1/6	0/3	0/2	0/1	0/6	3/20	0/21	0/5	0	0/6	5/106	4.7
Nyafutu	3/11	0/10	0	0	0	0/8	0/9	0	0/1	1/2	0/8	0/25	1/26	1/18	0/1	0	6/119	5.0
Dukuase	10/66	2/52	1/24	1/50	0/12	1/37	0/11	1/2	0/3	0/2	0/9	1/89	5/117	3/46	1/15	1/17	27/552	4.9
Odortom II	2/38	3/34	6/30	0/14	2/47	6/97	4/57	0/5	0/1	0/2	0/2	4/20	13/66	9/51	4/23	3/29	56/516	10.8

NS = Not sampled

in first 8 villages

1974 M	1974 J	1974 J	1974 A	1974 S	1974 O	1974 N	1974 D	1975 J	1975 F	1975 M	1975 A	1975 M	Total	%
0	0	0	0	0	0	0	1/1	0	0	0	0	0	1/4	—
0/4	0/3	1/8	0	0/13	0/10	0/27	1/22	0/14	0/3	0/4	0/2	0	23/271	8.5
0/3	0/3	2/8	0/1	0	0	0/6	0/12	1/7	2/17	2/9	0/6	0	24/355	6.8
0/62	1/25	0/3	0/4	0/1	0	0	0/1	0/5	0/53	0/24	1/57	0/25	25/1338	1.9
0	0	0	0	0	0	0	0	0/2	0/12	0/4	0	0	2/54	3.7
0/1	0/2	0	0/9	0/10	0/9	0/2	1/22	0/20	1/38	0/20	2/12	0/2	40/335	11.9
0/13	0/8	0/3	0/6	0/2	0/2	0/7	0/14	4/68	2/40	1/41	1/21	3/18	37/592	6.2
1/5	5/23	8/53	2/12	0/8	0/19	0/54	8/56	44/552	16/225	7/80	1/10	2/28	248/2440	10.2

B. rohlfsi by trematodes other than *S. haematobium* were relatively low: 2.1% in the first 8 villages and 1.1% in the second 8 villages. In the former group, relatively high rates of xiphidio-cercarial infections occurred only from April to the end of July 1973. In that period, these larvae probably originated from the large tadpole populations seen in sampled *Ceratophyllum* masses, where densities of *B. rohlfsi* were also high. For the entire period of baseline sampling in all 16 villages, the total non *S. haematobium* infections were 108 xiphidio, 8 echinostome, 6 lophocercous, 5 longifurcate holostome, and 3 amphistome type cercariae. Mixed infections between *S. haematobium* and xiphidio-cercariae were found in 3 snails.

Snail population fluctuations and numbers of infected snails by village

Tables 4 and 5 show the monthly numbers of mature *S. haematobium* infections in all *B. rohlfst* collected from each village. Among the first 8 villages, the great majority of snails (2440) and mature infections (248) came from Akotui West. Water contact sites sampled at this village were situated along part of a narrow, sheltered stream inlet with abundant growths of *Ceratophyllum* in the littoral zone. The second and third highest numbers of mature infections came from the villages of Kuma Kuma (40 infections) and Asakeso (37 infections), villages also located along narrow stream inlets, but with only light and moderate growths of *Ceratophyllum*, respectively. In these 3 villages, most of the snail infections occurred during early to mid-drawdown periods in pocket-shaped water contact sites. Fewer mature infections came from Poakwe Pawmpawmnya (25 infections), Kasa (24 infections), and Fatem (23 infections), villages located close together in semi-sheltered locations near the southern tip of the Pawmpawm branch. Poakwe Pawmpawmnya was initially a village with heavy *Ceratophyllum* growth, which accounts for the high catches and numbers of infected snails from March until the end of August 1973. Thereafter, the density of the plant became greatly reduced around the village and thus monthly snail catches and numbers of infected snails also dropped off sharply. Very few snails were collected from Kwabia and Pawmpawmnya I, villages located along wide-open, exposed sections of the lake. Snails were collected in these two villages only during rising water and early to mid-drawdown periods when emergent vegetation cover existed around the water contact sites.

Among the second 8 villages, numbers of snails and mature infections were high only at Odortom II and Dukuase. These two villages are located adjacent to each other in the extreme north-western sector of the project area where *Ceratophyllum* in the littoral zone is extremely dense. Most of the infections came from Odortom II (56 infections), where water contact sites are located along a sheltered stream inlet. Most of the snails were collected at Dukuase in water contact sites that were semi-sheltered; however, because of the greater wind and wave action in these sites, miracidial penetration into snails was hindered, and therefore numbers of mature snail infections were much lower (27 infections). In both villages, snails with mature infections were found during ten different months. The third highest number of mature infections came from Dawa Kofi (20 infections), a village located by a sheltered inlet-marsh. All but two mature infections were detected there during early to mid-drawdown periods. Much lower numbers of mature infections were collected at Akokoma (8 infections), Tamayeso (5 infections), and Nyafutu (6 infections), villages in semi-sheltered coves with only slight *Ceratophyllum* growth in sampled sites. Very few snails were collected from Atortorsi (none infected) and no snail was found at Asikoko. Although Atortorsi is located in a narrow, sheltered, non-stream inlet, it is situated on the steep eastern shore and water contact sites there have no *Ceratophyllum.*

DISCUSSION

Data collected to date indicate that both the palm-mat and modified man–time techniques are appropriate means of sampling in the Volta Lake. On a comparative basis, the palm-mat technique is more sensitive in collecting snails (*2*). It is better adapted for deep water sampling, for sampling in sites with little or no vegetation, and for collecting young snails. Palm-mat sampling can, however, only be conducted in areas where palm trees occur naturally. Palm-mat sampling would therefore not be suitable for sampling in all sectors of the Volta Lake, or in such other man-made lakes as Lake Nasser or Lake Kainji. The modified man–time method is simpler and requires less time and logistic support. The latter technique also allows for collection of egg masses and direct recording of snail–plant associations.

Our results on snail–vegetation association in the lake confirm earlier reports that *Ceratophyllum* has always been the main plant supporting the largest populations of *B. rohlfsi.* As early as 1969, Paperna (*10*) listed *Ceratophyllum* as the most important plant in the lake for the vector snail, followed by *Pistia* and *Scirpus.* Later studies by Odei (*6*) on the distribution of *B. rohlfsi* in different sectors of the lake, led him to conclude that the presence of *Ceratophyllum* is almost an indicator plant for the presence of the snail. In another study over 24 months, Odei (*7*) collected *B. rohlfsi* in the lake from various materials in the following percentages: *Ceratophyllum,* 47.9; palm leaves (fish traps), 21.7; wood, logs, twigs, 14.0; *Polygonum,* 7.9; *Pistia,* 5.1; mud, 3.4. On the other hand, our present results show that *Pistia* and *Scirpus* are now of minor malacological importance. *Polygonum,* however, is probably more important in promoting large populations of *B. rohlfsi* than either our or Odei's sampling results of snail–plant collections indicate.

We have observed that: (1) dense growths of *Polygonum,* although they do not directly attract snails, act as wind and wave barriers around water contact sites, creating sheltered habitats for the snails; (2) within opened areas bounded by *Polygonum, Ceratophyllum* normally invades and grows; (3) the roots and hollow stems of *Polygonum* provide shelter and protected surfaces for oviposition; and (4) rotting *Polygonum* serves as an ideal bottom substrate and snail food source.

In water contact sites, the concentration of snail infection very close to the shore is probably due to a number of factors. Firstly, most human activity occurs near shore, especially playing and swimming by children; therefore, miracidial discharge would also be highest there. Secondly, even when human activity occurs in deeper water, some of the miracidia released move towards the shore because of radial dispersion and others are swept in by the local daytime convection air currents. Thirdly, a high proportion of snails in water contact sites with vegetation are also concentrated very close to the shoreline. Fourthly, the shoreline itself, combined with any existing side vegetation, would act as a rebounding edge to increase miracidial density near shore (*1*).

Since no differences in water quality were detected in the different months, the sharp reduction in *B. rohlfsi* densities during the rising water periods seems to be the result of physical factors. The rapid flooding strands populations of the snail in deep water. Migration towards the inshore areas of water contact sites is further hampered by the narrow channels through the dense emergent vegetation. Even if snails do reach inshore areas, the environment is often too unstable or polluted there for the snails to multiply.

The rapid expansion of *B. rohlfsi* populations in most water contact sites each year from November to February is thus due to the return of more favourable environmental conditions: slower water fluctuation, less stagnant water, more pocket-shaped habitats bounded by *Polygonum,* and more *Ceratophyllum* growth.

The high natural infection rates of *S. haematobium* in *B. rohlfsi* can be attributed to the extreme susceptibility of the lake snail to the lake strain of the parasite and also to the confined activity and high frequency of human contact in the water contact sites. In routine host-parasite experiments at the

Table 6. Mean monthly pre-intervention transmission potentials of all sampled water contact sites containing snails with mature cercariae

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Percentage of positive water contact sites	34.1	26.4	25.0	20.5	11.9	11.3	14.5	11.9	2.8	2.9	11.1	18.9
Transmission potentials	17.8	13.8	13.1	10.7	6.2	5.9	7.6	6.2	1.5	1.5	5.8	9.9

Anyaboni field station, it was common to achieve infection rates exceeding 75% in *B. rohlfsi* exposed in mass to an average of 4 or more lake strain miracidia per snail. In small, protected water contact sites such as pockets or short channels, the probability of snails coming into contact with miracidia is naturally high. Even when just a few snails are present in such sheltered sites, the chance of at least one becoming infected is also relatively high. This was observed from our data. Out of 79 separate occasions when only one or two snails were collected from channel, type 11, or pocket-shaped water contact sites, on 10 occasions one snail with mature *S. haematobium* cercariae was found. While few snails can cause high transmission in small water contact sites, in other larger, more open sites, high numbers of snails can result in little or no transmission; therefore, for water contact sites in the Volta Lake, there is no such thing as a single theoretical threshold number of snails below which successful transmission would not be expected to occur.

From Tables 4 and 5, it is possible to group the 16 sampled villages into three main categories of cercarial transmission potential as follows: (1) little or no transmission throughout the year (Asikoko, Pawmpawmnya I, Atortorsi); (2) moderate, mostly seasonal transmission (Kwabia, Poakwe Pawmpawmnya, Akokoma, Nyafutu, Fatem, Kuma Kuma, Tamayeso, Dawa Kofi, Kasa); and (3) heavy transmission throughout most of the year (Asakeso, Akotui West, Dukuase, Odortom II).

In assessing the reliability and sensitivity of the snail sampling data in relation to the differing human prevalence rates of *S. haematobium* determined for the same villages, it was found that these parameters were significantly correlated (unpublished data).

Table 6 summarizes the monthly potentials of cercarial transmission in the 16 villages combined from snail sampling data thus far obtained. These potentials are calculated from the percentages of the different water contact sites sampled each month that were found to contain at least one snail with mature *S. haematobium* infection. It can be seen that the highest transmission season occurs from December to April. In this period, the most dangerous months (in decreasing order) are January, February and March, April, and December.

If human migration does not become a significant factor, it would seem that successful control of cercarial transmission of *S. haematobium* in lakeside villages can keep the incidence of new human infections very low. The question is, therefore, whether it is possible and feasible to control cercarial transmission in the Volta Lake? From the ecological findings reported here, we conclude that cercarial transmission control is both possible and feasible. It is possible because transmission is extremely focal in all villages. It is feasible because most transmission occurs only in water contact sites, very close to shore, only in certain habitats, and usually for no longer than 5 or 6 months a year.

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RÉSUMÉ

ÉTUDES ÉCOLOGIQUES DE *BULINUS ROHLFSI*, HÔTE INTERMÉDIAIRE DE *SCHISTOSOMA HAEMATOBIUM* DANS LE LAC VOLTA

De mars 1973 à mai 1975, des enquêtes ont été effectuées sur l'écologie de la transmission de cercaires par *Bulinus truncatus rohlfsi* dans le lac Volta. On a procédé à l'échantillonnage des mollusques dans 8 villages riverains du lac grâce à des pièges standardisés en feuilles de palmier disposés aux points de contact de l'homme avec l'eau; ces pièges étaient laissés en place pendant deux jours. L'échantillonnage des mollusques a été étendu en février 1974 à 8 autres villages. Dans ces derniers, l'échantillonnage était effectué aux points de contact avec l'eau par une modification de la technique homme-temps d'Olivier & Sneidermann.

En raison des fluctuations constantes du niveau du lac, les points de contact avec l'eau n'étaient jamais stables et se déplaçaient chaque mois sur des distances considérables. On a vite remarqué que ces changements rapides du tracé du rivage influençaient profondément l'écologie du mollusque vecteur et la transmission des cercaires. En définitive, trois phases écologiques distinctes ont été identifiées pour chaque cycle lacustre: la phase de montée des eaux, située entre juillet et novembre, la phase comprenant le début et la première moitié de l'abaissement de l'eau, compris entre novembre et avril, et la phase finale d'abaissement d'avril à juillet. Au cours de chacune de ces phases, les points de contact avec l'eau variaient ainsi considérablement quant à leur forme et leur végétation aquatique. Il s'agissait principalement de canaux longs et étroits dans la végétation émergeante au cours de la phase de montée des eaux, de poches dans la végétation émergeante au cours de la deuxième phase, et de larges plages ouvertes, au-delà de la végétation émergeante à la phase finale d'abaissement des eaux.

En ce qui concerne le nombre de mollusques infectés découverts, il variait selon la phase écologique; il était maximal au cours de la deuxième phase dans les points de contact avec l'eau, en forme de poches; beaucoup plus faible au cours de la dernière phase (et limité aux seuls endroits où *Ceratophyllum* poussait dans l'eau) et infime pendant la période de montée des eaux.

Ceratophyllum était de loin la plante préférée par *B. rohlfsi*; en effet, 68,5% et 83,5% de la totalité des spécimens recueillis par échantillonnage au moyen de nattes de palmes et par la méthode modifiée homme-temps, respectivement, provenait de cette plante aquatique.

Dans tous les points de contact avec l'eau où il y avait des mollusques infectés, la grande majorité de ces derniers ont été recueillis très près du rivage. Il n'en a jamais été trouvé qu'un très petit nombre à des distances dépassant 15 mètres du rivage, dans de l'eau dépassant 1 mètre de profondeur.

Si l'on considère la transmission des cercaires village par village, elle était la plus intense et la plus étendue dans les villages situés le long de criques abritées où le vent était le plus faible et l'eau la plus calme, modérée et principalement saisonnière dans les villages situés dans des points semi-abrités tels que de petites baies, et faible sinon nulle dans les villages situés sur des parties du rivage largement ouvertes sur le lac.

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Importance of the aquatic weed *Ceratophyllum* to transmission of *Schistosoma haematobium* in the Volta Lake, Ghana*

R. K. KLUMPP[1] & K. Y. CHU[2]

Results of 5 years of sampling for Bulinus rohlfsi *in human-water contact sites of villages along the Volta Lake, Ghana, have confirmed that the aquatic macrophyte,* Ceratophyllum, *is the most important ecological factor for sustaining high levels of cercarial transmission of* Schistosoma haematobium. *Data available so far indicate that growth of this weed largely determines the size of the snail populations. Increasing density of* Ceratophyllum *correlates with increasing levels of cercarial transmission potential in the water contact sites and of* S. haematobium *infection in the village populations.*

Soon after the filling of the man-made Volta Lake in 1966, *Schistosoma haematobium* spread rapidly throughout most branches of the lake and soon became a public health problem. Early research into the epidemiology and transmission of the disease by Paperna (*1*) and also by C. R. Jones and M. A. Odei (unpublished data), revealed that infection rates in humans and the vector snail, *Bulinus rohlfsi*, were highest in areas where the submerged weed *Ceratophyllum demersum* was present in considerable density. Later malacological work by Paperna (*2*) showed that the weed was the most important plant for promoting large populations of vector snails. Odei (*3*) mapped the *Ceratophyllum* distribution throughout the Volta Lake and concluded that the weed was almost an indicator plant for the presence of *B. rohlfsi*. Odei (*4*) also established that this snail was the only intermediate host for the infection in the lake.

Working in a UNDP/WHO Schistosomiasis Research and Control Project in the Pawmpawm and Afram branches of the Volta Lake, Klumpp & Chu (*5*) found that, when sampling was conducted by palm-leaf traps (palm mats) and dip-nets, over 68% and 83%, respectively, of all *B. rohlfsi* collected came from *Ceratophyllum*. Other aquatic plants were of malacological importance each year only during the period from November to March when the lake was receding from its annual peak.

Analysis of data collected in the Project suggests a high degree of positive correlation between the degree of *Ceratophyllum* growth in lakeside village water contact sites, positivity of these sites, and levels of infection in humans living in the same villages.

MATERIALS AND METHODS

Collection of snails and calculation of Ceratophyllum *density*

Monthly pre- and post-intervention snail sampling and ecological surveys were conducted and maintained in the main human-water contact sites (WCSs) of 16 study unit villages in the project area (Fig. 1). These surveys began in March 1973 in 8 villages. Snails were collected in WCSs using standardized palm-leaf mats (*6*). The number of WCSs sampled in each village ranged from 3 to 6. In January 1974, another 8 villages were added to give wider coverage to the northwestern sector of the project area where prevalence and intensity of *S. haematobium* infection in humans were highest. In each of the latter villages, snails were collected by 4 men using dip-nets in the two most heavily used WCSs. In both groups of villages, these pre-intervention surveys continued until May 1975 when the control of cercarial transmission by focal mollusciciding began in WCSs of all 26 study unit villages. Control by chemotherapy began in October 1975, and water supplies were made available to 7 of the villages at about the same time, by drilling bore-wells.

For each WCS surveyed, sketch maps were made showing the surface area, shape, location, vegetation distribution, and other ecological information. When snails were collected, a record was made of the sampling area within the WCS in which they were

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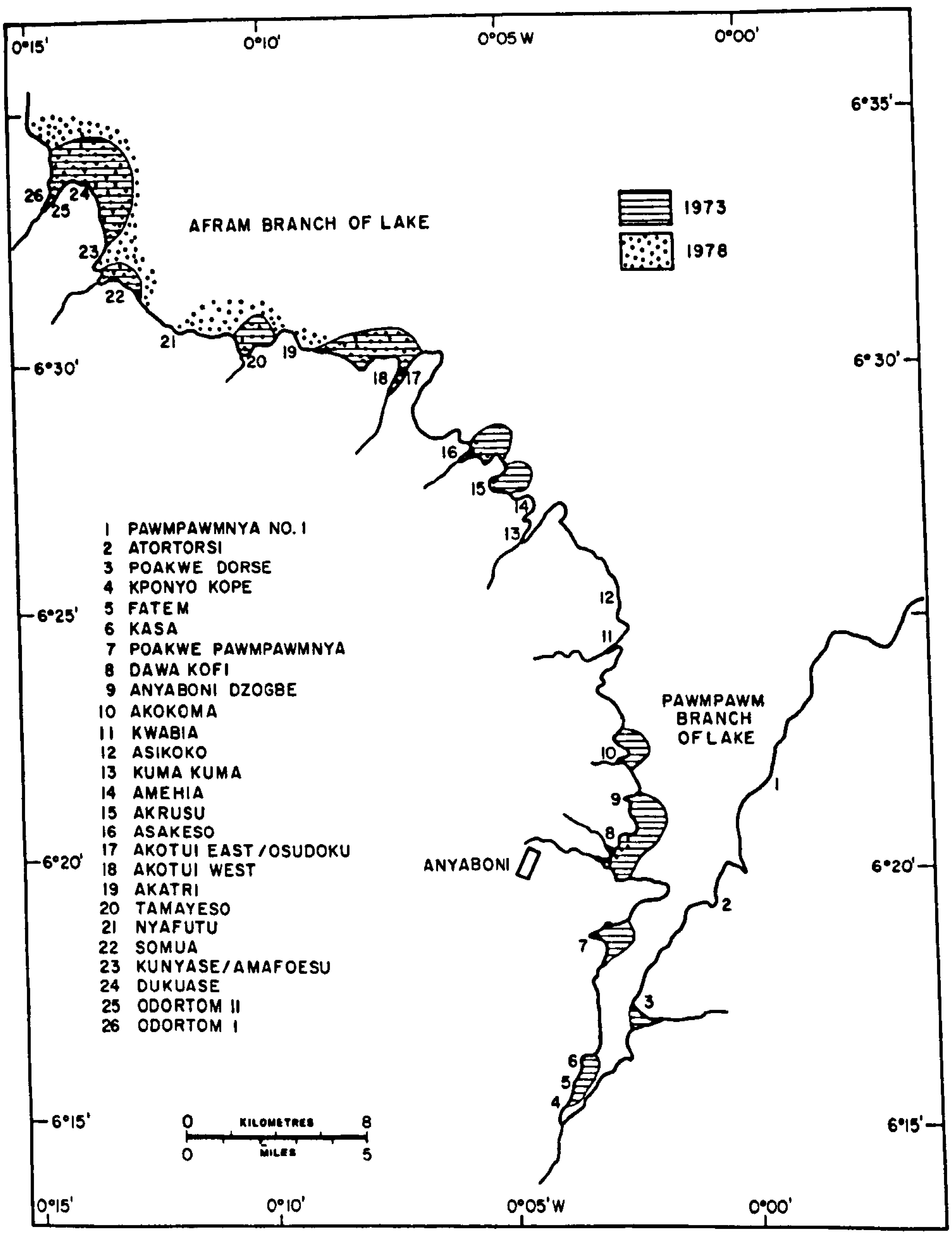

Fig. 1. Project area showing changes in *Ceratophyllum* distribution in the littoral zone between 1973 and 1978.

found and also of the vegetation from which they were collected. The snails were then taken to the field laboratory, crushed between glass slides, and examined for evidence of both mature and immature *S. haematobium* cercariae. Details of this work have been presented elsewhere (*5*).

It was not practical to make measurements of the *Ceratophyllum* biomass when the snail sampling surveys took place; however, the maps of the WCSs were accurate enough to allow for a simple quantitative assessment of the weed density in each. We have ranked this density as follows: no *Ceratophyllum* = 0; little = 1; medium = 2; heavy = 3. Each year from April to August (the open beach season), *Ceratophyllum* was usually the only weed present in the littoral zone of the lake. Thus, it was easy to determine its density rank by simple inspection of our maps. During the high-water period from September to November each year, *Ceratophyllum* density was more difficult to assess. This was because the main growth of the weed was offshore and within the WCSs the weed, when present, usually existed as numerous floating fragments or stationary clumps. But the density rank could be accurately ascertained by inspection of the maps, forms showing snail catches according to the type of vegetation, and information indicating whether the weed was growing offshore. The overall mean density of the weed in each village was calculated by adding up the monthly ranks of the weed for each WCS sampled and then dividing this sum by the total number of WCSs.

Use of epidemiological data

Epidemiological data on human prevalence rates and geometric means of *S. haematobium* eggs per 5 ml of filtered urine were taken from project records. For comparing *Ceratophyllum* density and the snail findings with the above data, we used the human data from Survey 4—the last of two full pre-intervention surveys, which ended in late 1974. The epidemiological index is defined here as the product of prevalence (%) and the geometric mean of egg density in positive cases for all age groups of people examined per village.

RESULTS

Changes in Ceratophyllum *growth*

Fig. 1 shows the geographical distribution of *Ceratophyllum* in the project area in 1973 and 1978. For the purpose of illustration, the growth limits from shore to deep water are shown about 10 times the actual limits. The limits between the villages are drawn to scale.

Initially, the weed was widely distributed. But after 1973, *Ceratophyllum* began dying off in and around most lakeside villages in the Pawmpawm branch (comprising study units (s.u.) 1–14). It first disappeared from Fatem (s.u. 5) and Kasa (s.u. 6) in 1975 and from Kuma Kuma (s.u. 13) in 1976. It grew in dense masses at Poakwe Pawmpawmnya (s.u. 7) in 1973 but could be found there only as scattered fragments in 1977. During the latter period, the weed also began dying off at Dawa Kofi (s.u. 8) and Akokoma (s.u. 10). In the Afram branch villages (comprising s.u. 15–26), *Ceratophyllum* started to disappear from Akrusu (s.u. 15) and Asakeso (s.u. 16) in late 1976, but remained in medium to heavy densities in all other villages except Akatri (s.u. 19). It increased in distribution and density at Tamayeso (s.u. 20) and Nyafutu (s.u. 21), becoming very thick in both places after 1975. By early 1978, *Ceratophyllum* was first noted growing in Akatri, where it appeared in light density.

The relationship between Ceratophyllum *density and snail density*

Yearly changes in *Ceratophyllum* density and numbers of *B. rohlfsi* collected in the 16 villages are presented in Table 1. This period covers 2 years of pre-intervention sampling, beginning in June 1973, and 3 years of post-intervention sampling. Since sampling in the second 8 villages did not begin until January 1974, data for the 1973–74 and 1974–75 periods were included only for the comparable months of January –May, respectively. This 5-month period represents most of the high-transmission season, when most snails and most infected snails were collected each year. In the post-intervention period of molluscicidng, all months were included.

The villages have been grouped according to similar patterns of *Ceratophyllum* growth and changes in density. Longitudinally, the results show a clear association between the total numbers of snails during the pre-intervention period and the degree of *Ceratophyllum* growth in the sampled WCSs. In the villages where the weed did not grow, total snail catches were extremely low despite abundant growth of rooted *Polygonum* and of numerous grasses in sampled sites each year from September to February or March. In the 4 villages where *Ceratophyllum* died off rapidly, the calculated density of the weed decreased by 43% after the first pre-intervention year, the numbers of *B. rohlfsi* collected dropped by almost 50%, and the number infected with mature *S. haematobium* cercariae fell by 75%. *Ceratophyllum* density remained light to moderate in Dawa Kofi, Akokoma, and Asakeso between the first and second year. In the same period, the total numbers and the numbers of infected *B. rohlfsi* also remained about the same.

Table 1. Yearly changes in the number of mature *Schistosoma haematobium* infections in *B. rohlfsi* per number of all *B. rohlfsi* collected and mean density rank of *Ceratophyllum* (in parentheses) according to the pattern of *Ceratophyllum* growth in 16 villages

Study units (villages) with different patterns of *Ceratophyllum* growth	Pre-intervention period		Post-intervention period		
	1973–74	1974–75	1975–76	1976–77	1977–78
Pawmpawm branch of lake					
None 01, 02[a], 11, 12[a]	3/42 (0)	1/22 (0)	0/15[b] (0)	0/9[b] (0)	0/5[b] (0)
Rapid die-off 05, 06, 07, 13	60/1094 (0.75)	15/530 (0.43)	5/128[c] (0.14)	1/53 (0.04)	0/63[b] (0)
Gradual die-off 08[a], 10[a], 16	37/431 (1.45)	32/383 (1.54)	3/107 (0.43)	0/57 (0.39)	1/1 (0.05)
Afram branch of lake					
Light to heavy 20[a], 21[a]	6/61 (0.69)	5/122 (0.88)	3/160 (1.56)	0/307 (1.94)	1/409 (2.21)
Remaining heavy 18, 24[a], 25[a]	197/1378 (2.08)	139/1593 (2.12)	3/211[d] (1.67)	2/270[d] (2.03)	1/134[d] (2.56)

[a] Includes data only for the period January to May during 1973–74 and 1974–75.

[b] Mollusciciding not carried out.

[c] All 5 positive snails from one lesser-used WCS; mollusciciding not conducted in that site on a regular basis.

[d] Mollusciciding operations 3 times every 2 months.

There was a decrease in infected snails at Asakeso due mainly to the excessive flooding there during October and November 1974. This made cercarial transmission diffuse and light until 1975. At Tamayeso and Nyafutu, the weed began to increase in distribution and density between the first and second year, which led to increasing numbers of *B. rohlfsi*. At Akotui West, Dukuase, and Odortom II, the density of *Ceratophyllum* remained moderate to heavy; the total number of *B. rohlfsi* increased from 1378 to 1593 but the number infected dropped from 197 to 139. This reduction, like that at Asakeso, was attributed to the rapid lake flooding of the foreshore in 1974. The people using one main WCS sampled at Akotui West were forced to move from their compounds after the structures were inundated in October. Thereafter, they had no further contact with the WCS although sampling there was maintained until June 1975.

In the post-intervention period of monthly or more frequent focal mollusciciding, the numbers of infected snails were greatly reduced in all villages. The ever changing lake level kept shifting the WCSs horizontally along the drawdown area so that the sites were never quite the same in successive months. Even after successful mollusciciding in a WCS with heavy growth of *Ceratophyllum*, new snails would quickly enter the site in washed-in fragments of the weed from offshore. The more rapid the lake regression, the more rapid the snail invasion. Thus, snail control *per se* was impossible in such a habitat—transmission control was our goal (*8*).

Correlation between Ceratophyllum *density and cercarial transmission*

From earlier studies (*5*), it was learned that the best long-term indicator of cercarial transmission potential in a lakeside village was the percentage of WCSs found "positive" per total number of WCSs sampled. Since WCSs were well defined and generally less than 600 m² in area, our criterion for a WCS to be positive was if at least one *B. rohlfsi* infected with mature *S. haematobium* cercariae was collected from that site during each period of monthly snail sampling.

This percentage of WCS positivity was considered a more valid measure of comparing cercarial transmission potential between villages than either the total number of infected snails or the percentage of infected snails collected. There were two main reasons for this. Firstly, in some villages, especially Poakwe Pawmpawmnya, most of the infected snails collected came from just one or two WCSs used exclusively by a small fraction of the village population over a short period and therefore would not have been as accurate a measure of transmission potential for the entire village as finding fewer infected snails from more WCSs over a longer period. Secondly, the percentage of snails found infected in WCSs was generally independent of overall snail density; a village showing a high percentage of infected snails based on a low number of total snails did not necessarily have a higher transmission potential than a village where a low percentage of infected snails came from a much larger number of total snails.

Fig. 2 shows the result of plotting the total mean *Ceratophyllum* density rank of the sampled sites for each village in the pre-intervention period against the percentage of WCSs found to be positive. Until the *Ceratophyllum* density rank reached about 1.5 (medium density) the percentage of positive WCSs increased almost linearly, but beyond that the increase was very rapid. It was found that a third degree polynomial regression gave a good fit of the data for the full range of values.

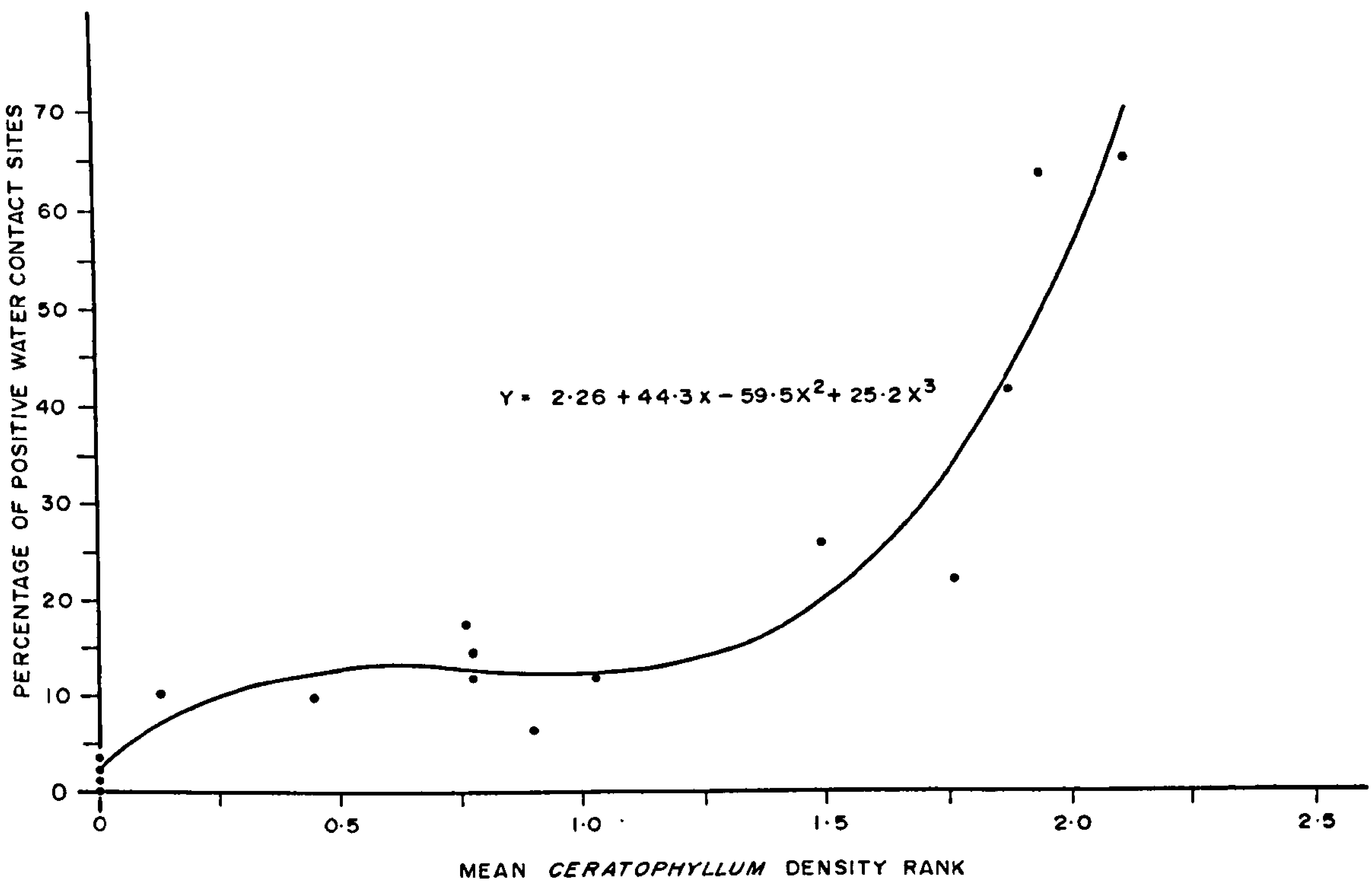

Fig. 2. Relationship between *Ceratophyllum* density and cercarial-infested water contact sites.

Fig. 2 can be described as follows. In the villages where *Ceratophyllum* was absent, very few WCSs were found to be positive since very few snails were ever found, regardless of season or other types of vegetation. In the villages where the weed grew in light density, the percentage of positive WCSs was higher but not entirely correlated with *Ceratophyllum* density. Almost all the infected snails were found each year between December and March in foci of pocket-shaped WCSs, usually bounded on the sides by solid *Polygonum* extending to water depths of 1 metre or more. In the centres of these protected WCSs, *Ceratophyllum* grew in patches or scattered fragments. Few positive WCSs were detected in these latter villages each year between April and July in the low-water period after the water receded beyond the limits of the emergent plant growth and WCSs became open beaches along sandy or muddy shores. *Ceratophyllum* patches or fragments were soon washed ashore by increased wave action, and hence, populations of *B. rohlfsi* greatly contracted in the exposed habitat. But in the villages with moderate to heavy *Ceratophyllum*, the weed survived well in and around WCSs during the entire open beach season. Heavy growth of the weed restricted human water contact to well defined points near shore, lessened wave action, and sustained relatively large populations of the snail. In this type of habitat, the probability of finding at least one infected *B. rohlfsi* was high every month.

However, when *Ceratophyllum* density became so heavy that the weed grew in a solid mass along the shore from shallow water to depths exceeding 5 metres, cercarial transmission would become interrupted. This was observed in the Project Comparison Area further north-west in the Afram branch (Klumpp & Chu, unpublished data). There, extremely heavy growth of the weed caused the water to become stagnant and often foul, and the weed itself died off temporarily during the hot months of February–May. In these conditions, which were unusual for the lake as a whole, snail populations quickly contracted, and people using the lake kept changing their sites of water contact along the shoreline to the least polluted points.

Table 2. Correlations between *Ceratophyllum* density, cercarial-infested water contact sites, and infected people in 16 villages during the pre-intervention period

Villages (study units) with different patterns of *Ceratophyllum* growth	Mean weed density rank per sampled WCS	Percentage of sampled WCSs found positive	Survey 4 (1974) Prevalence (%)	Geometric mean egg output (per 5 ml of urine)	Epidemiological index[a]
Pawmpawm branch of lake			(1)	(2)	(3)
None					
(01) Pawm. No. 1	0	1.2	33.3	17.4	5.8
(12) Asikoko	0	0	36.6	15.5	5.7
(11) Kwabia	0	2.5	71.9	33.3	23.9
(02) Atortorsi	0	3.3	77.6	41.9	32.5
Rapid die-off					
(13) Kuma Kuma	0.13	10.4	72.2	32.3	23.3
(05) Fatem	0.45	9.9	70.6	45.2	31.9
(06) Kasa	0.76	17.3	74.3	37.2	27.6
(07) P. Pawmpawmnya	0.90	6.5	68.3	36.6	25.0
Gradual die-off					
(10) Akokoma	0.78	11.8	68.1	31.6	21.5
(08) Dawa Kofi	1.50	25.8	84.6	44.9	38.0
(16) Asakeso	1.77	21.7	71.4	31.6	22.6
Afram branch of lake					
Light to heavy					
(21) Nyafutu	0.78	14.7	88.1	53.5	47.1
(20) Tamayeso	1.03	11.8	87.5	77.6	67.9
Remaining heavy					
(24) Dukuase	1.88	41.2	89.6	61.1	54.7
(18) Akotui West	1.95	63.0	77.7	63.9	49.6
(25) Odortom II	2.12	64.7	95.2	75.9	72.2
Correlation coefficients (r)					
Ceratophyllum density		0.874[b]	0.622[d]	0.668[c]	0.679[c]
Percentage of positive WCSs			0.570[d]	0.694[c]	0.697[c]

[a] Epidemiological index (3) = (1) x (2)/100.
[b] $P < 0.001$
[c] $P < 0.01$
[d] $P < 0.05$

Correlation between Ceratophyllum *density, cercarial transmission, and human infection*

These positive correlations are presented in Table 2. Similar degrees of correlation resulted when both the pre-intervention *Ceratophyllum* densities and the percentages of positive WCSs were compared with human prevalence rates, geometric means of egg density, and their products, the epidemiological indices, in the 16 villages. Despite expected discrepancies between the results of snail sampling in an unstable environment compared with more stable endemic levels of *S. haematobium* infection, the figures indicate that the baseline snail sampling results correlate closely with differing levels of endemicities in all but 4 villages: Atortorsi, Asakeso, Tamayeso, and Nyafutu. In each of the first 2 villages, less than 50 people were examined in Survey 4,[a] the lowest number among all project area villages. In the last 2 villages, low percentages of positive WCSs contrasted with high prevalence rates. Since snail searches were always fairly exhaustive (1 man-hour per WCS per visit), it seems clear that in Tamayeso and Nyafutu the epidemiological indices were already very high before snail sampling started, and the period of snail sampling coincided with reduced *Ceratophyllum* growth in the WCSs when snail populations were low.

Theoretically, it would have been preferable to compare the snail data and *Ceratophyllum* densities with human incidence rates in the villages. However, this was not possible. Initial pre-control prevalence rates were so high in most villages, especially in the Afram branch, that very few children were negative

[a] The last of the two full pre-intervention surveys, which ended in late 1974.

for *S. haematobium* infection. In the largest villages and lower transmission villages, crude incidence data are available from consecutive prevalence surveys, but these data are difficult to analyse because of the possibility of false positives and false negatives as well as the high degree of migration by the people, both within and outside the project area.

DISCUSSION

It is now confirmed that the presence of *Ceratophyllum* is the main ecological factor determining the duration of cercarial transmission each year in the Volta Lake. The weed is now confined mainly to the southern sectors of the lake and is most dense in the large Afram branch. *Ceratophyllum* grows best in deep stream inlets of the lake receiving seasonal discharge from nearby escarpments or hills. This discharge probably supplies the nutrients required by the weed; the narrow inlets offer protection against wind and wave action. The weed cannot maintain growth in exposed areas of the lake where the slope of the foreshore is minimal. Perhaps that is why *Ceratophyllum* has never become established in the flat savanna branches of the lake, or exposed sections in the project area.

Many distinct and synergistic factors most likely affect *Ceratophyllum* distribution and density in the lake. We lacked sensitive water-quality testing equipment and were unable to measure nutrient levels or other important water-quality parameters with our field kits. Thus, the reasons for the rapid disappearance of *Ceratophyllum* in the Pawmpawm branch of the project area are still unknown. This die-off was preceded by a die-back of *Pistia*, also a floating plant, in the southern tip after 1971. Before that, it extended in a solid mat almost up to Kponyo Kope (s.u. 4). Hall & Okali (7) studied the *Pistia* decline and attributed it mainly to declining levels of dissolved phosphate and nitrate around the mouth of the Pawmpawm River. The continuing drought of 1976 and 1977 further curtailed stream and river discharge into the Pawmpawm branch, and this has probably caused a concomitant decrease in nutrient levels in the entire southern section of the branch. However, we noticed that *Ceratophyllum* reductions at Fatem, Kasa, and Poakwe Pawmpawmnya began when the lake was still high and the Pawmpawm River flowing. The die-off may be only temporary, and a few continuous years of above-average stream and river discharge into the branch might lead to a resurgence of the weed.

The reasons for the increase of *Ceratophyllum* around Tamayeso, Nyafutu, and more recently Akatri, are also unclear. Wide belts of the weed were already present in the deep water in the Tamayeso stream inlet during 1974 and 1975 when the lake level was at its highest ever peak. The subsequent fall in the level of the lake during 1976 and 1977 just shifted the shoreline into this wide stationary mass. But no such off-shore weed mass was observed at Nyafutu or Akatri during 1974 or 1975. The weed first became a problem at Nyafutu in 1976 and was first seen in medium density at Akatri in January 1978.

Since *Ceratophyllum* is such a dangerous weed for promoting schistosomiasis in the Volta Lake, its removal from populated areas should be a very effective way of reducing or even controlling transmission. From our experience, this is possible and practical only in areas where it grows in light density. In areas where it grows in medium to heavy density, its removal is extremely difficult, even with the full participation of the villagers. The wide distribution and heavy weight of water-logged *Ceratophyllum* makes removal by hand or with rakes a very difficult, time-consuming, and expensive operation. Incomplete removal of the weed could actually increase transmission by creating larger areas in which children could swim and play, with *B. rohlfsi* surviving in the remaining patches and bottom growths. Moreover, because *Ceratophyllum* often extends as a solid mass from shore to deep water, its removal would have to be maintained fortnightly in WCSs during lake draw-down because of the receding water. As a result of this constant fluctuation, control by herbicides has also proved ineffective (Klumpp, Rafatjah, & Chu, unpublished report). Mechanical removal would be impractical, owing to the numerous submerged and projecting tree stumps all over the lake shallows.

For the meantime, the only effective way to control *S. haematobium* transmission in lakeside villages with fairly heavy *Ceratophyllum* growth is by focal mollusciciding with the 2-aminoethanol salt of niclosamide (Bayluscide) carried out 3 times every 2 months during most of the year, combined with a selective programme of population chemotherapy using metrifonate.

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RÉSUMÉ

RÔLE DE LA PLANTE AQUATIQUE *CERATOPHYLLUM* DANS LA TRANSMISSION DE *SCHISTOSOMA HAEMATOBIUM* SUR LES RIVES DU LAC VOLTA (GHANA)

Une série d'enquêtes par sondage ont été faites de 1973 à 1978 en vue de déterminer la densité des populations de *Bulinus rohlfsi* aux points de contact avec l'eau (WCS) les plus fréquentés dans 16 villages situés sur les rives du Lac Volta au Ghana. Les deux premières années d'enquête ont été consacrées à la collecte de données de base. En mai 1975 a débuté une série d'interventions visant à réduire la transmission de *Schistosoma haematobium* dans les 26 villages de la zone du projet, notamment par l'application focale de molluscicides. Des campagnes chimiothérapiques destinées à des groupes particuliers de population ont en outre été menées dans tous les villages dès octobre 1975 et elles ont été complétées par un approvisionnement en eau, des puits ayant été creusés dans sept villages. Les opérations d'échantillonnage des populations de mollusques ont été régulièrement effectuées chaque mois jusqu'à et après la campagne de lutte, et elles se poursuivent actuellement.

L'un des premiers résultats des enquêtes menées sur les mollusques a été la découverte du facteur écologique qui, à lui seul, est principalement responsable de l'extension des populations de *B. rohlfsi*. Il s'agit d'une plante aquatique, *Ceratophyllum*, et il a été établi que le nombre des mollusques et celui des personnes infectées étaient au plus haut niveau dans les villages situés sur des rives où cette plante était abondante; la transmission des cercaires et le taux d'infection dans la population humaine augmentaient avec la densité de *Ceratophyllum*.

Les auteurs ont groupé les villages selon la distribution et la densité de *Ceratophyllum*, cette dernière étant évaluée selon une échelle variant de 0 à 3 (0: absence de *Ceratophyllum*; 1: faible densité; 2: densité moyenne; 3: forte densité). La densité était relativement facile à déterminer, notamment par l'examen des cartes qui avaient été dressées des points de contact avec l'eau (WCS) et sur la base de divers éléments d'information recueillis lors des enquêtes. Pour chaque village, la densité moyenne annuelle a été calculée en additionnant les degrés mensuels de densité pour tous les WCS et en divisant le total par le nombre des WCS.

Le potentiel de transmission cercarienne pour chacun des 16 villages a également été défini comme équivalant au pourcentage des WCS où un mollusque au moins avait été trouvé porteur de cercaires adultes de *S. haematobium* par rapport au nombre de WCS surveillés. Un degré élevé de corrélation s'est établi entre la densité moyenne de *Ceratophyllum* et le pourcentage des WCS positifs. De plus, chacun de ces éléments s'est révélé en corrélation avec le taux de prévalence de l'infection à *S. haematobium* dans le village et la moyenne géométrique de l'excrétion d'œufs, ainsi que l'indice épidémiologique calculé en fonction des paramètres précédents (tableau 2).

L'élimination de *Ceratophyllum* des points de contact avec l'eau n'a guère été possible que là où sa densité était faible. Il est difficile, lorsque cette algue prolifère, de la faire disparaître manuellement car cela mobiliserait de nombreux bras pendant un temps appréciable. La végétation de *Ceratophyllum* constitue souvent une masse compacte qui va du fond du lac à la surface, et ceci depuis le rivage jusqu'à des profondeurs dépassant 5 m, d'où son volume et son poids considérables. La destruction de la plante par des herbicides ne peut non plus être envisagée en raison des fluctuations incessantes dues aux variations du niveau des eaux du lac selon la saison. Ces fluctuations imposeraient d'ailleurs, en cas d'élimination manuelle, la répétition des opérations tous les 15 jours à l'époque où l'eau se retire progressivement.

Le seul moyen efficace de lutte contre la transmission des cercaires aux points de contact avec l'eau où *Ceratophyllum* est abondant est, dans le contexte actuel, l'application de molluscicides 3 fois au cours de chaque période de 2 mois pendant presque toute l'année, parallèlement à un programme sélectif de chimiothérapie.

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